NEW ZEALAND'S WHITEBAIT FISHERY: SPATIAL AND TEMPORAL VARIATION IN SPECIES COMPOSITION AND MORPHOLOGY.

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Table of Contents

List of Figures

Chapter Four

Chapter Five

Appendices

List of Tables

Appendices

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ABSTRACT

Whitebait are iconic in New Zealand. They comprise a culturally, commercially and recreationally important fishery when netted returning from their marine life phase. The five species comprising the New Zealand whitebait catch are inanga (*Galaxias maculatus*), koaro (*G. brevipinnis*), banded kokopu (*G. fasciatus*), giant kokopu (*G. argenteus*) and shortjaw kokopu (*G. postvectis*). Four of the five whitebait species are now ranked as 'declining or nationally vulnerable' and there is increasing concern that the fishery has declined considerably over the past few decades due to multiple stressors. Current management of the fishery is based on limited science, regulations are over 20 years old and treat the fishery as a whole apart from the West Coast of the South Island. There is limited information on species composition within the 2.5-3.5 month fishing season. This thesis examines these issues in a geographically-widespread study.

Whitebait were sampled from 92 rivers throughout New Zealand over six months (July to December) in 2015. A subset (8) of these rivers were sampled again during the 2016 whitebait season. Over 95,000 fish from approximately 420 samples were processed (20,000 of which were measured for morphological data). Regional and temporal variations were found in the physical characteristics used to identify species at the whitebait stage. Of the five whitebait species, inanga whitebait were easiest to identify from catches. Differentiating giant kokopu from koaro and banded kokopu whitebait proved difficult. Genetic analysis proved vital for accurate identification of shortjaw kokopu whitebait.

Inanga made up the highest proportion of whitebait in samples from across New Zealand, but koaro and banded kokopu made substantial contributions in some rivers and regions at particular times of the year. Buller was found to have the highest within-region variability in species composition due to the relatively high proportions of non-inanga whitebait. There was a strong positive association between the abundance of koaro and kokopu whitebait in samples with forest cover and unmodified land area. Latitude and coast (east vs. west) were found to affect whitebait length, with fish length increasing with latitude. Non-whitebait species observed in samples included smelt, freshwater shrimp, glass eels, adult eels, juvenile and adult bullies, yellow-eyed mullet, and lamprey.

The timing of giant kokopu and banded kokopu whitebait migrations was earlier in the North Island than in the South Island. Whitebait lengths, body depth, and condition varied throughout the six month period with initially lower lengths and condition increasing and then decreasing again. The peak in length and condition corresponded with the peak migrations.

The species composition of whitebait samples varied significantly in only one of the rivers sampled in successive years. In comparing the current composition to a study from 50 years ago, the whitebait catch included higher proportions of banded kokopu and lower proportions of koaro and inanga than previously. Examining the North Island, and east and west Coast of the South Island separately, there were higher proportions of koaro and banded kokopu, and lower proportions of inanga in 2015 than previously.

My study provides the first New Zealand-wide view of the morphology of whitebait, and new insights into the current species composition of the whitebait fishery. It shows there is substantial spatial and temporal variation in the species composition of the whitebait catch. Other key findings include the discovery of high proportions of non-inanga species in regions other than Buller and Westland and the first genetically confirmed identification of shortjaw kokopu whitebait, and giant kokopu in many rivers. These findings have important implications for freshwater fish conservation and management of the whitebait fishery.

CHAPTER ONE: GENERAL INTRODUCTION AND METHODOLOGY

1.1 GENERAL INTRODUCTION

1.1.1 Overview of whitebait research

Whitebait, fishes of the genus *Galaxias*, are iconic species of New Zealand. They comprise a cultural, commercial and recreational fishery and are one of the few fisheries based on a post-larval stage rather than on adults. There is increasing concern that the fishery has declined considerably over the past few decades because of multiple stressors that affect populations and their replenishment, which may have differentially affected the five species that make up the fishery. Understanding the species composition and morphology of the fishery in different regions and catchments of New Zealand is a necessary precursor to delineating both natural variability and effects of impacts. Unfortunately, there is limited information on species composition, wide- and local-scale variability, and temporal sequences of variability within the 2.5-3.5-month fishing season. Furthermore, current management of the fishery is based on limited science, regulations are over 20 years old that treat the fishery as a whole apart from the West Coast of the South Island. Taken together there is huge concern with this perceived decline, current management and sustainability of this important fishery. This thesis examines these issues in a geographically widespread study across New Zealand.

Whitebait are diadromous and in late winter and spring, great numbers of juveniles migrate back into freshwater from their marine larval stages. As the small fish enter rivers they are harvested by nets in streams and rivers by recreational, commercial and cultural fishers (McDowall, 1984). Although statistics on this fishery are not recorded, there is considerable anecdotal evidence that catches have declined in the past few decades. Overfishing, habitat degradation, loss of migratory pathways and introduced fish species have been the main factors implicated in their decline (McDowall, 1990; Rowe et al., 1992),

The five species comprising the New Zealand whitebait catch are inanga (*Galaxias maculatus*), koaro (*G. brevipinnis*), banded kokopu (*G. fasciatus*), giant kokopu (*G. argenteus*) and shortjaw kokopu (*G. postvectis*). Of these, the vast majority of captured whitebait are inanga, with the remaining four species making up a variable and much smaller component (McDowall & Eldon, 1980). As a result of the importance of *G. maculatus* to the fishery, and the relative ease of studying them, more is known about the biology of *G. maculatus* than the other four species (Charteris & Ritchie, 2002).

There are significant differences in the migratory behaviour of the five species (McDowall & Eldon, 1980). For example, each has different migration patterns based on varying water characteristics such as temperature (McDowall & Eldon, 1980; Richardson et al., 1994), pH (McDowall & Eldon, 1980), turbidity (Boubée et al., 1997; Rowe & Dean, 1998; Richardson et al., 2001) and velocity (Baker & Smith, 2015). Other characteristics affecting migration patterns are connectivity (McDowall, 1966), tidal height and phase, and flood events (McDowall & Eldon, 1980). Furthermore, the presence and abundance of adult whitebait in a catchment are thought to influence river selection of returning whitebait (Baker & Montgomery, 2001). The migration patterns have been found to be complex but data available from these studies are limited to only a few regions.

Recent studies have improved our understanding of the life history and ecology of whitebait species. These studies have determined life stages that may limit recruitment, and how impacting factors can be mitigated. For example, recent studies have examined the effects of connectivity restrictions (e.g., dams, weirs and culverts) on diadromous fish populations (Jellyman & Harding, 2012), the upstream passage of migrating whitebait (Doehring et al., 2011), and the movement of adults within catchments (Allibone et al., 2003). Other studies have examined removal of connectivity restrictions and rehabilitation of fish passages (Doehring et al., 2012; Franklin & Bartels, 2012; David et al., 2014). It has been suggested that degraded instream and riparian habitat are likely factors limiting recruitment (Jowett et al., 2009), and studies have identified the location of these critical habitats for adults (McDowall et al., 1996; Bonnett & Sykes, 2002), including spawning habitat (Allibone & Caskey, 2000; Charteris et al., 2003) and how to enhance and rehabilitate it (Hickford & Schiel, 2013, 2014). Other studies have examined the effects of introduced species such as trout (Townsend, 1991; McIntosh, 2000; McIntosh et al., 2010) and mosquito fish *Gambusia affinis* (Rowe et al., 2007), and eradication of these species (Pham et al., 2013) for native galaxiids.

Despite these research studies there are many gaps in the knowledge about the complex life histories of these fish, and further research is critical to understanding their population dynamics and fishery returns.

1.1.2 Landscape modification and limiting stages in lifecycle

Since European colonisation in New Zealand, there has been extensive modification of freshwater ecosystems that has caused large declines in many native freshwater fish populations. Inanga, koaro, and giant kokopu are ranked as 'At Risk, Declining' and shortjaw kokopu as 'Nationally Vulnerable' (Goodman et al., 2013). Modifications to freshwater ecosystems include changes to landscape, vegetation and water quality with the intensification of dairying, agriculture, deforestation, draining of wetlands, damming of rivers, water abstraction, river channelisation, introduction of exotic fish, and commercial and recreational harvesting (Dudgeon et al., 2006; Joy, 2014; Holmes et al., 2016). These impacts are considered to be the reasons for the decline in whitebait populations, but the relative contributions of each have not been distinguished and some may be location-specific.

Whitebait species have complex life stages across a large range of ecosystems. Population sizes are regulated by the number of breeding adults, the number of eggs produced, the number of larvae that go to sea, the conditions at sea during the larval stage, the conditions inland where adults live, such as habitat quality, migratory passage and barriers, and the number of fish harvested. Survivorship probably varies temporally during all these stages, but the contribution of the different impacts to any perceived whitebait decline is unknown (McDowall, 1996b).

Expansion of agriculture, dairy farming and increased urbanisation has resulted in extensive habitat degradation (Dudgeon et al., 2006). Freshwater systems act as a drainage network so terrestrial contaminants make their way into waterways through one-way flows to the sea (Schiel & Howard-Williams, 2016). This affects freshwater, estuarine and marine ecosystems, all of which function as important stage-specific habitat for whitebait species (McDowall, 1996a). Increased sedimentation and nutrients reduce water quality, can cause eutrophication, lead to decreased oxygen levels, create changes in food webs and result in a loss of diversity (Smith, 1999; Jowett et al., 2009). Contaminated flows of heavy metals, pesticides, and hydrocarbons can have chronic and cumulative effects on fish communities (Thrush, 2004). Large-bodied galaxiids such as banded kokopu, and shortjaw kokopu are forest specialists so deforestation and the loss of riparian margins create fragmented habitat, effect decomposition, hydrology, temperatures, disturbance regimes, terrestrial subsidies, and reduce water quality, food availability, and suitable instream cover (Goodman, 2002; Baker & Smith, 2007).

Dams, weirs and culverts not only restrict or prevent upstream passage of whitebait and the movement of adults within a catchment (Doehring et al., 2011; Jellyman & Harding, 2012), but also can affect flow regimes and disrupt spawning of whitebait which rely on riparian development of eggs and elevated flows to trigger spawning events (Franklin et al., 2015).

Irrigation and water abstraction can lower the water table and river levels and when combined with regulated flows can cause long term mouth closure of braided rivers, typical of the east coast of the South Island, and prevent whitebait migration. Less water and reduced flows in rivers and streams can alter permanence and habitat size, resulting in elevated water temperatures, and an increase in sediments, thus reducing water quality and suitable habitat for adult whitebait (Foote, 2015; McHugh et al., 2015).

Draining of swamps and wetlands has ruined critical adult habitat for giant kokopu and banded kokopu, particularly in Canterbury where they are thought to have been abundant (McDowall, 1990), and has destroyed ecosystems where important processes like denitrification occur (Hefting, 2013).

River channelisation can restrict flows resulting in increased velocities, scouring of river banks, increased sedimentation, and buildups of substrates (Allan, 2004; Elosegi, 2013). This disturbance changes river morphology, reducing habitat complexity, the available habitat for aquatic biota resulting in marked changes to invertebrate communities (Quinn et al., 1992; Williamson et al., 1992; Negishi et al., 2002).

The introduction of trout has caused widespread reductions in the distribution and abundance of native galaxiid fish through competition and predation (McIntosh et al., 2010). There is little co-occurrence of trout and native galaxiids (Townsend, 1991), with trout being found to alter galaxiid behaviour (Bonnett & McIntosh, 2004) and benthic communities that are critical food sources (McIntosh, 2000; McIntosh et al., 2010). Furthermore, there are ongoing problems of range expansion of trout (McDowall, 2006). Similarly, the introduced pest species *G. affinis* causes high mortality of juvenile inanga in warmer water (Rowe et al., 2007), and koi carp have been found to reduce adult galaxiid habitat and water quality (Goodman et al., 2013).

With increasing numbers of whitebaiters on rivers and no restrictions on the quantity of whitebait that can be harvested, the whitebait fishery adds further pressure to the survivorship of whitebait (McDowall, 1996b).

1.1.3 Diadromy, dispersal and metapopulations

Diadromous fish have life stages in both marine and freshwater environments. Over 250 such species exist worldwide and although relatively rare globally, there is a high level of diadromy in New Zealand (McDowall, 1992). There are three types of diadromy: anadromy where species spawn in freshwater but spend most of their lives in the sea (e.g., salmonids), catadromy where species spawn in the ocean and spend most of their lives in freshwater (e.g., eels) and amphidromy where species migrate between freshwater and the sea in both directions, but not for the purpose of breeding (e.g., galaxiid 'whitebait' species) (McDowall, 1992, 2010).

The five galaxiid 'whitebait' species are amphidromous. Adults live in freshwater habitats, and spawn in estuarine (inanga) and riverine (koaro, banded kokopu, giant kokopu and shortjaw kokopu) environments. Spawning occurs on riparian margins amongst vegetation, debris, gravels and boulders, during high spring tides for inanga and in elevated flows for koaro, banded kokopu, giant kokopu and shortjaw kokopu. Eggs develop out of water for c. three weeks until re-submerged on the next spring tide or flood event when larvae hatch and are washed out to sea (Mitchell et al 1992; McDowall & Suren 1995). Larvae develop in the marine environment for 4-6 months (McDowall, Mitchell & Brother 1994; McDowall & Kelly 1999) before returning to freshwater as juvenile fish, which are commonly known as 'whitebait' (Allibone & Caskey, 2000; Charteris et al., 2003). Once in freshwater, that whitebait species that escape capture by whitebaiters and can climb past instream barriers continue to migrate upstream to adult habitats that (except for inanga) may be located considerable distances upstream.

For whitebait species to complete their life stages they must migrate between ecosystems over varying spatial and temporal scales. Of the life stages the least understood is the marine stage. Marine larval development is thought to give amphidromous fish a greater ability to disperse, allow them to use increased food availability with potential growth advantages, facilitate recolonisation after major disturbance, escape competition, and reduce predation pressure (McDowall, 2007; Hickford & Schiel, 2016). However, little is known about the distance that whitebait disperse, their survival at sea, and how often they return to their natal river. This is in part due to the small size of newly hatched larvae and the associated difficulties with tagging, mark and recapture or GPS tracking methods commonly used in fish dispersal studies (Lowe, 2010; Redlich, 2012).

Several studies have examined whitebait dispersal to gain an understanding of metapopulation dynamics. While some species of diadromous fish (e.g., salmon) return to their natal rivers (Keefer & Caudill, 2014) this seems unlikely for whitebait given their small size and limited swimming and sensory abilities (Hickford & Schiel, 2016). Despite that, juvenile whitebait have been found to respond to adult pheromone cues (Baker & Hicks, 2003). Furthermore, a study using otolith microchemistry to track dispersal pathways of whitebait found inter-regional movement from distinct populations on the east and west coasts of the South Island (Hickford & Schiel, 2016). This is further supported by spatial and temporal variability in pelagic larval duration and growth rate of whitebait (Hopkins, 1979; McDowall et al., 1994; McDowall & Kelly, 1999; Rowe & Kelly, 2009; Egan, 2017). Studies of inanga genetics have shown a lack of structure within New Zealand, Chilean and Falkland Island populations (Waters & Burridge 1999; Waters et al 2000) suggesting considerable marine dispersal and connectivity of populations.

Marine dispersal exposes developing whitebait larvae to the oceanic environment. New Zealand's coastal waters differ regionally in terms of productivity, temperature and oceanic currents. Differences between regions in upwelling intensity result in coastal waters on the South Island's west coast being more nutrient-rich than those on the east coast (Menge et al., 2003; Schiel, 2004). A latitudinal temperature gradient exists together with varying oceanic currents between regions (Chiswell & Rickard, 2011; Chiswell et al., 2015). Regional variations in the oceanic environment experienced by developing whitebait larvae are likely to be translated into differing growth, survival and dispersal characteristics.

1.1.4 The New Zealand Whitebait Fishery

The whitebait season in New Zealand is open from 15 August to 30 November with the exception of the West Coast of the South Island (1 September to 14 November), and the Chatham Islands (1 December to the end of February) (Eichelbaum, 2013).

There is much public interest in the fishery because of its value (McDowall, 1990). It is culturally important in that whitebait is taonga and has been fished traditionally dating back to New Zealand prehistory (McDowall, 1996b). With whitebait fetching over $100 per kilogram it has high commercial value as well as being a highly popular recreational fishery (Haggerty, 2007).

Management of the whitebait fishery has focused on preserving and maintaining stocks of fish. The only controls on the fishery are a restricted fishing season, the time of day whitebait can be fished (5am to 8pm) and limits on net sizes and the equipment that can be used (McDowall, 1996b). The West Coast fishery is managed separately from the rest of New Zealand with additional rules such as back markers, a reduced fishing season, and closed rivers (Whitebait Fishing Regulations 1994, www.legislation.govt.nz).

The restricted season on the West Coast was implemented in 1994 for conservation of later-migrating giant kokopu (McDowall, 1999a). There has been much criticism from whitebaiters that the data used to justify the shortened West Coast whitebait season were inaccurate, incomplete and out of date (McDowall, 1996b). Although, McDowall and Kelly (1999) updated this knowledge with a comprehensive study of the timing of the giant kokopu migration on the West Coast, little is known about the recruitment of the 'Nationally Vulnerable' shortjaw kokopu as it currently cannot be identified at the whitebait stage (Goodman et al., 2013). It is hoped that sampling large numbers of whitebait temporally from various regions throughout New Zealand combined with modern genetic techniques will allow identification of shortjaw kokopu whitebait.

Several studies have examined species composition of the whitebait fishery (Davis, 1980; McDowall & Eldon, 1980; Stancliff et al., 1988; Hanchet & Hayes, 1989; Rowe et al., 1992; McDowall, 1999a; Boubée et al., 2001; Campbell, 2015), but it has been over 50 years since the last widespread study (McDowall, 1965) which had limited spatial and temporal coverage, some important whitebaiting regions were missed entirely, kokopu were not identified to species, morphology parameters were not measured, and it is uncertain how many rivers were sampled and where. Although, later studies were more comprehensive that included multiple rivers and samples they were confined to particular regions (Rowe et al., 1992; McDowall & Kelly, 1999). Only two studies have been able to identify *G. argenteus* at the whitebait stage (McDowall et al., 1994; McDowall, 1999a) and one study *G. postvectis* (McDowall et al., 1994). These were not conclusive as there was no genetic confirmation of these species from the West Coast of the South Island. Although the New Zealand freshwater fish database show records of adult populations of both *G. postvectis* and *G. argenteus* in North Island rivers no published studies have identified these species at the whitebait stage (Fig. 2.1d, 2.1e). Catches in these studies were dominated by inanga but other species were also present at certain times of the year.

To effectively manage the whitebait fishery, current spatial and temporal components of variability in the composition and morphology of the whitebait catch must be understood. Knowledge of spatial variability is crucial because: important whitebaiting rivers and regions occur throughout New Zealand; oceanic conditions vary greatly around New Zealand; and there are regional differences in the timing of spawning and the start of marine dispersal (Taylor, 2002; Hickford & Schiel, 2016). Knowledge of temporal variability will inform future discussions about the timing and length of the whitebait open season, fill gaps in knowledge about the planktonic larval duration of some of the less common whitebait species, and help with understanding how temporally variable oceanic conditions influence the composition of the whitebait catch. A joint understanding of the spatial and temporal variability components will give an indication of the species and the morphology of whitebait coming back into adult populations and will provide further insight into dispersal.

This study has been structured to sample multiple rivers in different regions around New Zealand to understand the spatial and temporal components of species composition of the fishery. It also considers fish morphology, as it varies among species and regions. Although there has been research examining composition and morphology of whitebait, the only wide scale composition study was over 50 years ago (McDowall, 1965) and the morphology studies were limited to particular regions or specific rivers (McDowall & Eldon, 1980). There is also a current study being done to assess many morphological differences among fish and their otoliths (E Egan, PhD in progress).

1.1.5 Research Aims and Chapter Content

This thesis and its associated sampling program aimed to generate extensive new data to compare with historical records of the New Zealand fishery and to provide further insight into the dispersal and the structure of whitebait populations. It aimed to determine the timing of species migration into rivers and how this changes during the whitebait season, and how these might vary for the 5 whitebait species. Particular attention was directed at giant kokopu and shortjaw kokopu for which little is known.

The results of this research will help inform any future review of the whitebait fishery, particularly with regard to the spatial management of the fishery and the timing of the fishing season.

In Chapter 2, I give an overview of the natural history of the five whitebait species. I investigate identification techniques to differentiate between the 'whitebait' stages of the five amphidromous galaxiid species, as well as spatial and temporal differences in the appearance of these species and a genetic study to confirm species identifications.

In Chapter 3, I investigate the species composition of catches and morphometric parameters (length, weight and width) of the five species of whitebait and how these vary spatially over a six month period within and outside of the current whitebait season. I investigate inter- and intra-regional variability in species composition and morphology to understand the population structure of species.

Chapter 3 addresses several questions:

1. *What are the species composition, length, body depth and condition of whitebait entering rivers in the North and South Islands of New Zealand?*
2. *Do any environmental variables influence the species composition of whitebait entering rivers and streams?*
3. *Are there small-scale spatial differences in the species composition and morphology of the whitebait catch regionally and between rivers?*
4. *Which other species are found in the whitebait catch?*

In Chapter 4, I investigate the species composition of catches and morphometric parameters (length, weight and width) of the five species of whitebait and how these vary temporally over a six month period. I investigate inter- and intra-regional variability to understand the population structure of species, the timing of migration for different species. I compare these results with historical surveys to detect any shifts in species composition.

Chapter 4 addresses several questions:

1. *Are there small-scale temporal differences in the species composition and morphology of the whitebait catch?*
2. *Are the species composition and morphology of whitebait samples consistent within rivers from year to year?*
3. *Has the species composition of the whitebait fishery changed since it was surveyed by McDowall in the 1960s?*

1.2 METHODOLOGY

1.2.1 Study Design and Study Sites

During the 2015 whitebait season, whitebait samples (see below) were collected by me, members of the University of Canterbury Marine Ecology Research Group, experienced whitebaiters, the Department of Conservation, and Regional Councils. The temporal sampling programme was completed before, during and after the open whitebait season, roughly every two weeks from 1 July through 31 December. This programme included up to four rivers from each of the following regions: Bay of Plenty, Waikato, Hawkes Bay, Tasman-Nelson, Canterbury, Buller, Westland and Southland. Additional regions (Auckland, Coromandel, Taranaki, Manawatu -Wanganui, Wellington, Marlborough, and Otago) and rivers were sampled during the whitebait season as part of the spatial sampling programme (Fig. 1.1, Table 1.1, Appendix 1). Outside of season sampling was undertaken with a research permit from the Department of Conservation (44336-FAU).

A total of 92 rivers and streams were sampled throughout New Zealand in 2015 and a subset of these (8 rivers) were sampled again during the 2016 season. Sampling sites included important whitebaiting rivers, a subset of sites from past surveys, and a range of rivers of diverse characteristics (see Appendix 1). Two rivers (Waimea Creek, Westland and Aorere River, Tasman-Nelson) were included because a large number of adult *G. postvectis* had been observed in the catchment (NIWA, 2015) and this potentially improved the likelihood of detecting this species in the whitebait catch.

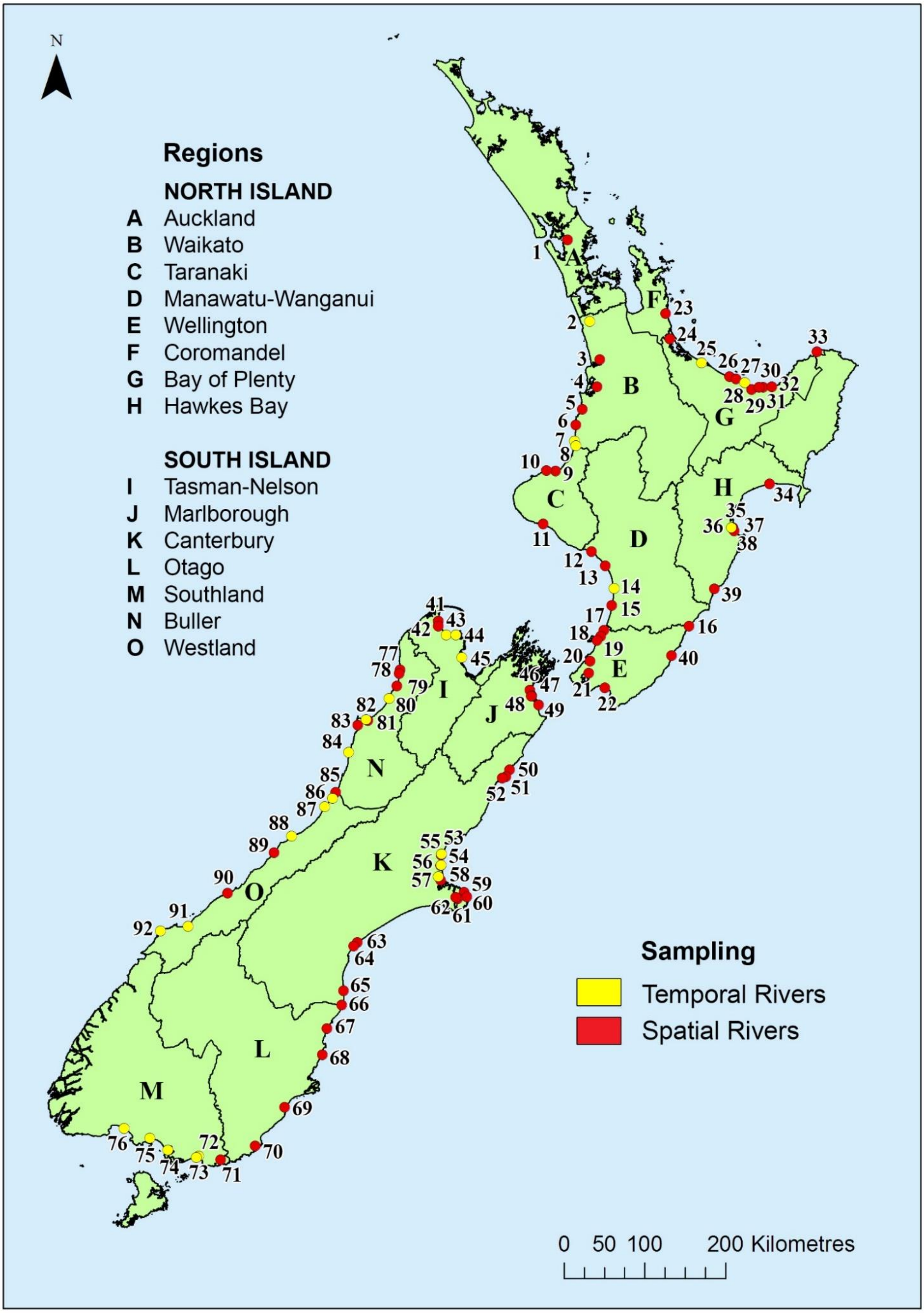


Figure 1.1. 92 whitebaiting rivers sampled throughout New Zealand during the 2015 whitebait sampling. Yellow = Temporal sampling, Red = Spatial sampling.

Table 1.1. Whitebaiting rivers sampled throughout New Zealand during the 2015 study showing spatial and temporal sites and rivers with numbers from Figure 1.1.

Region	River	River Number	Sampling Undertaken	Region	River	River Number	Sampling Undertaken	Region	River	River Number	Sampling Undertaken	Region	River	River Number	Sampling Undertaken
Auckland	Hoteo River	1	Spatial		Otara River	30	Spatial		Opara Stream	59	Temporal		Wanganui River	88	Temporal
	Waikato River	2	Temporal	Bay of Plenty	Waiaua River	31	Spatial		Le Bons Stream	60	Spatial		Okarito River	89	Spatial
	Waingaro River	3	Spatial		Waiotahi River	32	Spatial		Robinsons Stream	61	Temporal	Westland	Paringa River	90	Spatial
	Oparau River	4	Spatial		Whangaparaoa River	33	Spatial	Canterbury	Pawsons Stream	62	Spatial		Waiatoto River	91	Temporal
Waikato	Marokopa River	5	Spatial		Wairoa River	34	Spatial		Orari River	63	Temporal		Cascade River	92	Temporal
	Waikawau River	6	Spatial		Ngaruroro River, Tutaekuri River and Clive River (Mouths)	35	Spatial		Opihi River	64	Spatial				
	Awakino River	7	Temporal	Hawkes Bay	Tutaekuri River	36	Temporal		Waihao River	65	Spatial				
	Mokau River	8	Temporal		Clive River	37	Spatial		Waitaki River	66	Spatial				
	Onearo River	9	Spatial		Tukituki River	38	Spatial		Kakanui River	67	Spatial				
Taranaki	Waitara River	10	Spatial		Porangahau River	39	Spatial	Otago	Shag River	68	Spatial				
	Waingongoro River	11	Spatial	Wairarapa	Whareama River	40	Spatial		Taeri River	69	Spatial				
	Kai Iwi Stream	12	Spatial		Aorere River	41	Spatial		Owaka River	70	Spatial				
	Whangaehu River	13	Spatial		Parapara River	42	Spatial		Waikawa River	71	Spatial				
Manawatu - Wanganui	Rangitikei River	14	Spatial	Tasman - Nelson	Takaka River	43	Temporal		Titiroa River	72	Temporal				
	Manawatu River	15	Spatial		Wainui River	44	Temporal	Southland	Mataura River	73	Temporal				
	Owahanga River	16	Spatial		Motueka River	45	Spatial		Oreti River	74	Temporal				
	Otaki River	17	Spatial		Wairau River Diversion	46	Temporal		Aparima River	75	Temporal				
	Peka Peka Stream	18	Spatial	Marlborough	Wairau River	47	Spatial		Waiau River	76	Temporal				
Wellington	Waikanae River	19	Spatial		Opawa River	48	Spatial		Oparara River	77	Spatial				
	Pauahatanui Stream	20	Spatial		Awatere River	49	Spatial		Karamea River	78	Spatial				
	Hutt River	21	Spatial		Hapuku River	50	Spatial		Little Wanganui River	79	Spatial				
	Ruamahanga River (Lake Ferry)	22	Spatial		Lyell Creek	51	Spatial	Buller	Mokihinui River	80	Temporal				
Coromandel	Wentworth River	23	Spatial		Kowhai River	52	Temporal		Orowaiti River	81	Spatial				
	Tuapiro Creek	24	Spatial		Saltwater Creek	53	Spatial		Buller River	82	Spatial				
	Kaituna River	25	Temporal	Canterbury	Ashley River	54	Spatial		Okari River	83	Temporal				
Bay of Plenty	Tarawera River	26	Spatial		Waimakariri River	55	Spatial		Punakaiki River	84	Temporal				
	Rangitaiki River	27	Spatial		Styx River	56	Spatial		Taramakau River	85	Spatial				
	Whakatane River	28	Temporal		Avon River	57	Spatial	Westland	Waimea Creek	86	Temporal				
	Nukuhou River	29	Spatial		Heathcote River	58	Spatial		Hokitika River	87	Temporal				

Whitebait were captured with scoop nets and set nets that are commercially available for whitebaiting purposes (Fig. 1.2 a-c). All nets were of legal size and dimensions: circumference smaller than 4.5m on the inside of the net, maximum width of 6 metres, and maximum height of 3.5m. Nets did not take up more than a third of a channel width (Eichelbaum, 2013).

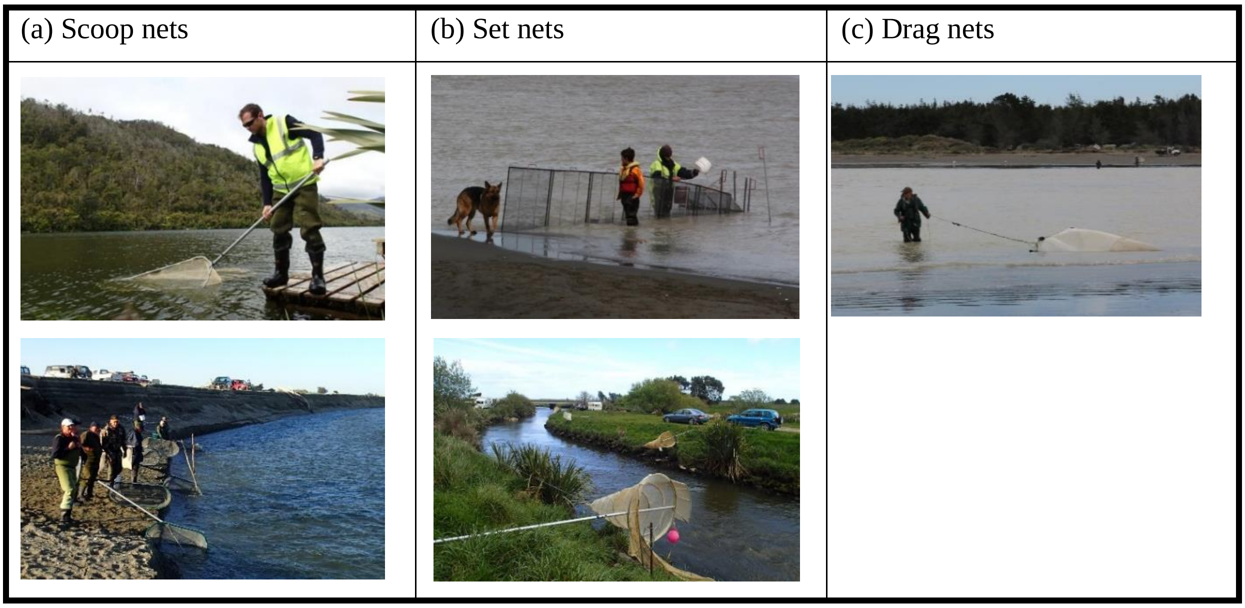


Figure 1.2. Types of nets used to catch whitebait in this study: a = scoop nets, b = set nets, c = drag nets.

Whitebait entering rivers and streams form shoals that are made up of mixed species (McDowall & Eldon, 1980; McDowall, 1996b). Where possible, multiple shoals were caught from each river before a subsample of 200 whitebait was taken from the total catch (Fig. 1.3 a & b). Some of the whitebait species are known to behave differently once captured (e.g., koaro climb to the top of whitebaiter's buckets; (McDowall & Eldon, 1980), so all fish in the catch were mixed thoroughly by hand before a subsample was taken. Whitebait samples were frozen in bags with enough water to cover all fish to prevent freezer burn (Fig. 1.4a). Waterproof labels were written in pencil and put into these bags along with additional labelling on the outside of each bag. Frozen fish were collected for transport using portable car freezers and frozen transport back to Christchurch. Samples were stored in two large walk in freezers at the university that were set to -16C (Fig. 1.4b).

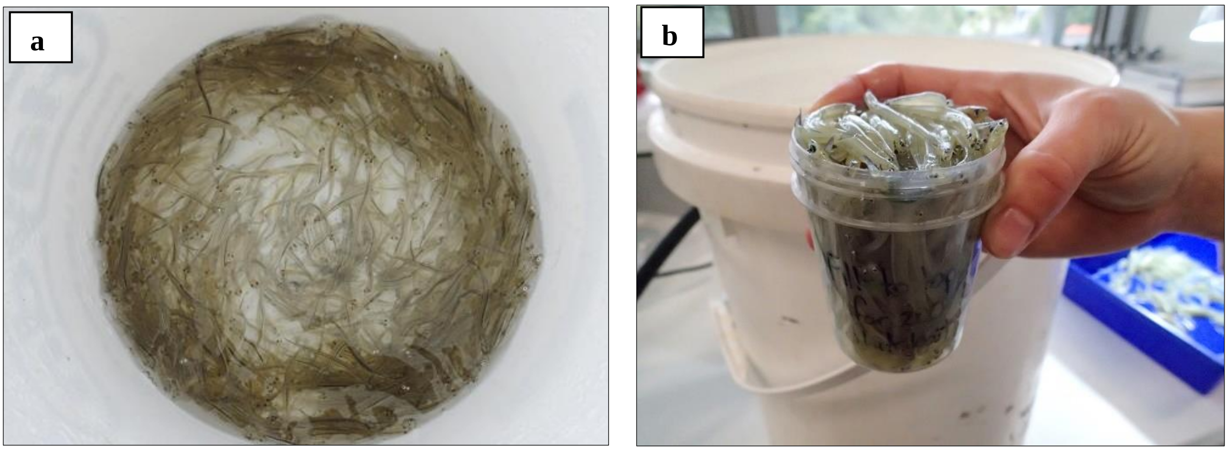


Figure 1.3. Bucket of whitebait caught over several hours of fishing (a), subsample of a known volume of approximately 200 whitebait taken from catches (b).

Waterproof field sheets were filled out to accompany each sample (see Appendix 2). These included metadata such as date, time period fished, place, weather conditions, time since last flood, total catch and fishing equipment used. The exact location of sampling sites were recorded with GPS. Potential biases in field sampling and laboratory processing are addressed in Appendix 3.

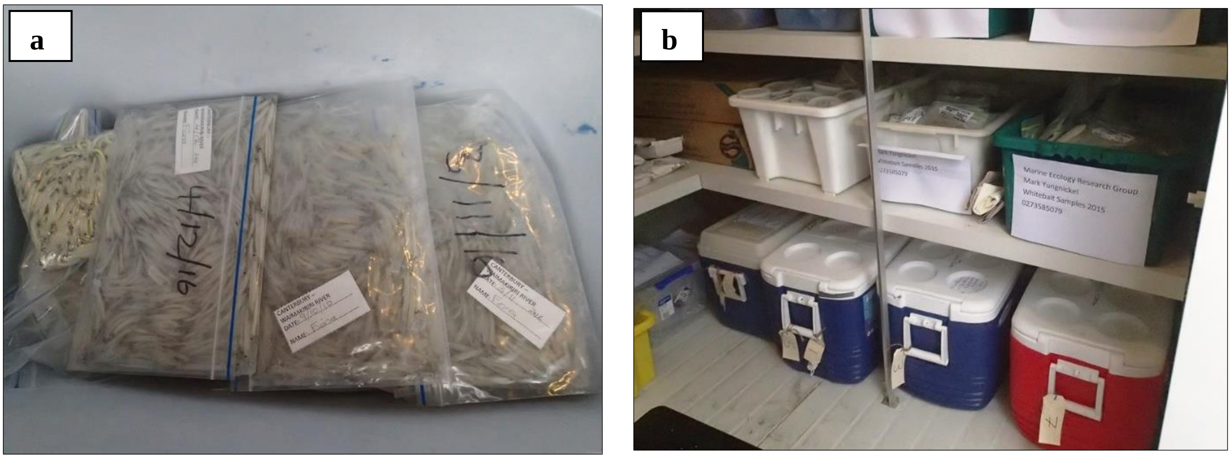


Figure 1.4. Whitebait were frozen flat in ziplock bags (a), whitebait were stored in chilly bins in large walk in freezers (b).

CHAPTER TWO: NATURAL HISTORY AND SPECIES IDENTIFICATION

Summary

- Adult whitebait species have very different characteristics
- There are regional and temporal variations in the characteristics used to identify species at the whitebait stage
- Of the five whitebait species inanga whitebait were easiest to separate from catches
- Differentiating giant kokopu from koaro and banded kokopu whitebait proved difficult
- Genetic analysis proved vital for accurate identification of shortjaw kokopu whitebait

2.1 NATURAL HISTORY OF WHITEBAIT SPECIES

There are approximately 35 fish species in the Galaxiidae family found throughout the Southern Hemisphere from Australia, Tasmania, New Caledonia, Lord Howe Island, New Zealand, Chatham, Auckland and Campbell Islands, Chile, Argentina, Tierra del Fuego, Falkland Islands and South Africa. Approximately twenty-two species of galaxiids exist in New Zealand, seventeen in the genus *Galaxias* and five in the closely related genus *Neochanna*. The patterns on the flanks of the first *Galaxias* species described were likened to the stars of a galaxy. Galaxiids have no scales and are typically small fish between 40-150mm in length. They have a single dorsal fin with a single rows of teeth in their jaws (McDowall, 1990, 2006).

Most of New Zealand's galaxiids are non-diadromous, but 5 species are amphidromous and together make up the whitebait catch. Additionally, smelt can also form an important part of the whitebait fishery in some rivers at certain times of the year (Ward et al., 2005). Although whitebait species and smelt mostly move between freshwater and marine ecosystems for different parts of their life cycles, they can also form landlocked populations where the larval stage occurs in lakes (McDowall, 2000). Although sharing a diadromous life history, the five galaxiid species that comprise the whitebait catch have different characteristics as adults (Table 2.1).

Inanga, *Galaxias maculatus*, are widespread throughout New Zealand (Fig. 2.1a) and although native are not endemic, being also found in Australia and South America (Berra et al., 1996). Adults live in coastal rivers, streams, lagoons and backwaters as they lack the climbing ability of the other four whitebait species (Baker & Boubée, 2006; Franklin & Bartels, 2012). Uniquely for the whitebait species, inanga are found in small to large shoals as adults, but can be solitary and secretive in swift-flowing locations (McDowall, 2000). They spawn in late summer and early spring in the upper reaches of estuarine areas among bankside riparian vegetation on spring tides (Hickford & Schiel, 2011). Eggs develop for 3-4 weeks before hatching on the next spring tide, and washing out into the marine environment. Juveniles (whitebait) return to freshwater after several months at sea and reach sexual maturity at 1 year of age (Hickford & Schiel, 2016). Inanga adults are the smallest of the whitebait species, growing to only 80-110mm (McDowall, 2000). Inanga have the shortest life span of the whitebait species with most 1 year old fish not surviving spawning (Stevens et al., 2016) , and only a few surviving until 2 or 3 years old (Burnet, 1965). Adults feed mainly on aquatic larval insects and crustaceans sourced from bottom, midwater, surface/terrestrial areas (Jowett, 2002). Inanga are tolerant of varying water temperatures (Richardson et al., 1994), salinities (Laurenson et al., 2012) pH levels (Glover et al., 2012) and suspended solids (Boubée et al., 1997) that are typical of lowland rivers. Inanga have a conservation status of 'At Risk – Declining', but have very large populations (>100,000 mature individuals) and low to high (10-70%) ongoing or predicted decline (Goodman et al., 2013). Although inanga are still widespread and abundant, their presumed decline may be due to extensive habitat degradation from intensification of agriculture and urbanisation in lowland areas. This has affected the quantity and quality of spawning habitat (Hickford & Schiel, 2013).

Table 2.1. Summary table of galaxiid whitebait species and common smelt.

Common Name	Inanga	Koaro	Banded kokopu	Giant kokopu	Shortjaw kokopu	Common Smelt
Species	*G. maculatus*	*G. brevipinnis*	*G. fasciatus*	*G. argenteus*	*G. postvectis*	*R. retropinna*
Endemic	No	No	Yes	Yes	Yes	Yes
Common size (mm)	80-110	160-180	200	300-450	150-200	90-110
Max age (year)	Mostly 1	15		Up to 50		3+
Sexual Maturity (year)	1	Probably 2 or 3	2 male, 3 female	Probably 2 or 3	Probably 2 or 3	2
Conservation status	At Risk – Declining	At Risk – Declining	Not threatened	At Risk – Declining	Threatened – Nationally Vulnerable	Not threatened
Climbing ability	Poor	Excellent	Good	Poor	Good	Poor

Koaro, *Galaxias brevipinnis*, are widespread throughout New Zealand (Fig. 2.1b) and are also found in Australia (O'Connor & Koehn, 1998). They occur from sea level to high elevations well inland as they have excellent climbing ability (Hayes, 1996). They are solitary and cryptic, favouring forested, clear, fast-flowing, boulder-cobble streams or inland lakes (McDowall, 2000). Spawning is thought to occur in late May under cobbles and boulders on riparian margins during high flows. Eggs develop and hatch on subsequent floods 3-4 weeks later and wash to sea before juveniles return to freshwater several months later (O'Connor & Koehn, 1998; Allibone & Caskey, 2000). Many landlocked populations exist in the North and South Islands, with larval development occurring within freshwater (McDowall, 2000; Rowe et al., 2002). Adult koaro are often 160-180mm in length and are thought to be long-lived to around fifteen years. They eat a diverse range of aquatic and terrestrial insects (McDowall, 2000). Koaro have a conservation status of ‘At Risk – Declining’ but with very large populations (>100,000 mature individuals) and low to high (10-70%) ongoing or predicted decline (Goodman et al., 2013). Although still widespread, koaro were once abundant in lakes, but declined greatly after the introduction of trout and common smelt (Rowe, 1993; Rowe et al., 2002).

Banded kokopu, *Galaxias fasciatus*, are endemic to New Zealand. Although they have a widespread distribution, they are largely absent from the east coast of the North and South Islands (Fig. 2.1c). Adults are common in small overgrown streams with slow-flowing pools. They are good climbers and can penetrate well inland, but most fish are found in lowland areas (Baker & Smith, 2007; McQueen, 2013). They are usually solitary and cryptic but can be found at high densities (West, 2005). Adults are commonly 200mm in length with males maturing at 2 years and females at 3 year+ (McDowall, 2000). Spawning has been observed from April to May among riparian vegetation during high-flows. After hatching during the next flood event, larvae develop in the marine environment before returning to freshwater several months later (Hopkins, 1979b; Mitchell & Penlington, 1982; Charteris et al., 2003). The diet of banded kokopu consists of terrestrial species such as beetles, ants and spiders as well as a diverse range of aquatic insect larvae (West, 2005). Banded kokopu have a conservation status of ‘Not Threatened’, with large stable populations (Goodman et al., 2013). Although widespread, they have declined substantially in range and abundance with limited distribution on the east coast of both islands due to habitat degradation such as deforestation in lowland areas (McDowall, 2000; Rowe et al., 2000) with juveniles sensitive to suspended solids (Boubée et al., 1997). However, their non-threatened status may be a result of their strong climbing ability to navigate past instream barriers, ability to form land-locked populations and the large populations found in the upper North Island.

Giant kokopu, *Galaxias argenteus,* are found throughout New Zealand, but are patchily distributed (Fig. 2.1d). They are widespread at low elevations, but rare in Northland and the east coast of both islands (Franklin et al., 2015). They inhabit small to medium sized gently flowing streams, pools, wetlands and lake margins with overgrown weedy boggy vegetation. They are thought to reach sexual maturity at two to three years (McDowall, 1990, 2000) before spawning in autumn and winter amongst riparian vegetation where eggs develop outside of the water until the next high flood (Bonnett & Sykes, 2002; Franklin et al., 2015). They are territorial and aggressive, and as adults they are the largest of the whitebait species, commonly reaching 300-450 mm, but have been found up to 580 mm. They are thought to be the longest lived whitebait species, up to 50 years old (McDowall, 2000). They are active predators eating a range of terrestrial animals as well as koura and aquatic insects (Bonnett & Lambert, 2002). Giant kokopu have a conservation status of ‘At Risk – Declining’ with large populations (20,000 - 100,000 mature individuals) and low to moderate (10-50%) ongoing or predicted decline (Goodman et al., 2013). They are now considered rare in many parts of New Zealand and are absent in catchments with development of agriculture and farming. Their decline is thought to be due to the loss of suitable cover and instability in their habitat and water flows (Bonnett & Sykes, 2002).

Shortjaw kokopu, *Galaxias postvectis*, are endemic to New Zealand. Adults are patchily distributed, more widespread in the North Island, but commonly missing from the east coast (Fig. 2.1e). Adults have specific habitat preferences of boulder streams covered by native forest and are solitary and nocturnal (McDowall, 1997; Goodman, 2002). They are thought to reach sexual maturity at 2 or 3 years of age. Spawning has been observed in May on riparian margins among stony substrate, vegetation and debris (Charteris et al., 2003). Shortjaw kokopu are 150-200 mm in length with the largest recorded fish at 350 mm (Goodman, 2002). Their diet is dominated by terrestrial invertebrates such as spiders, ants, moths, cicadas as well as instream caddisfly larvae (McDowall, 2000). Shortjaw kokopu have a conservation status of ‘Threatened - Nationally vulnerable’ with moderate to large populations (5000 - 20,000 mature individuals) and high (30-70%) ongoing or predicted decline (Goodman et al., 2013). Although widespread, very few populations are known, consisting of very few individuals. The loss of forested habitat is strongly associated with their decline, with few adults occupying modified habitat (McDowall, 1997; Goodman, 2002; Goodman et al., 2013).

Common smelt, *Retropinna retropinna*, are endemic to New Zealand. They have a widespread distribution, particularly in the upper half of the North Island (Fig. 2.1f). Another species of smelt (Stokell's smelt) has an overlapping distribution with common smelt in the Canterbury region. Smelt are not good climbers, but are strong swimmers and can penetrate well inland on rivers with low gradients (Leathwick et al., 2009; Franklin & Bartels, 2012). They are usually found in still or gently flowing waters of lake margins, lowland rivers, and estuaries where they form large shoals. Smelt spend the majority of life at sea apart from non-diadromous landlocked populations (Rowe & Taumoepeau, 2004; Ward et al., 2005). Sexual maturity is reached at 2-3 year of age where adults migrate into rivers during spring and summer. Eggs are laid on estuarine and river gravels where hatching occurs a few weeks later. They wash to sea and develop in the marine environment for a year before returning to the freshwater (Ward et al., 2005). Diadromous smelt are commonly 90-110mm but have been found to reach 165mm (McQueen, 2013). Juvenile fish feed on zooplankton whereas adults are generalists eating a diverse range of aquatic insects including chironomids, mysids, amphipods, and algae (Boubée & Ward, 1997). Common smelt are also known as "second class" whitebait or "cucumber fish" and are important to the whitebait fishery on the Waikato River (Ward et al., 2005). Common smelt have a conservation status of 'Not Threatened', with large, widespread, stable populations (Goodman et al., 2013).

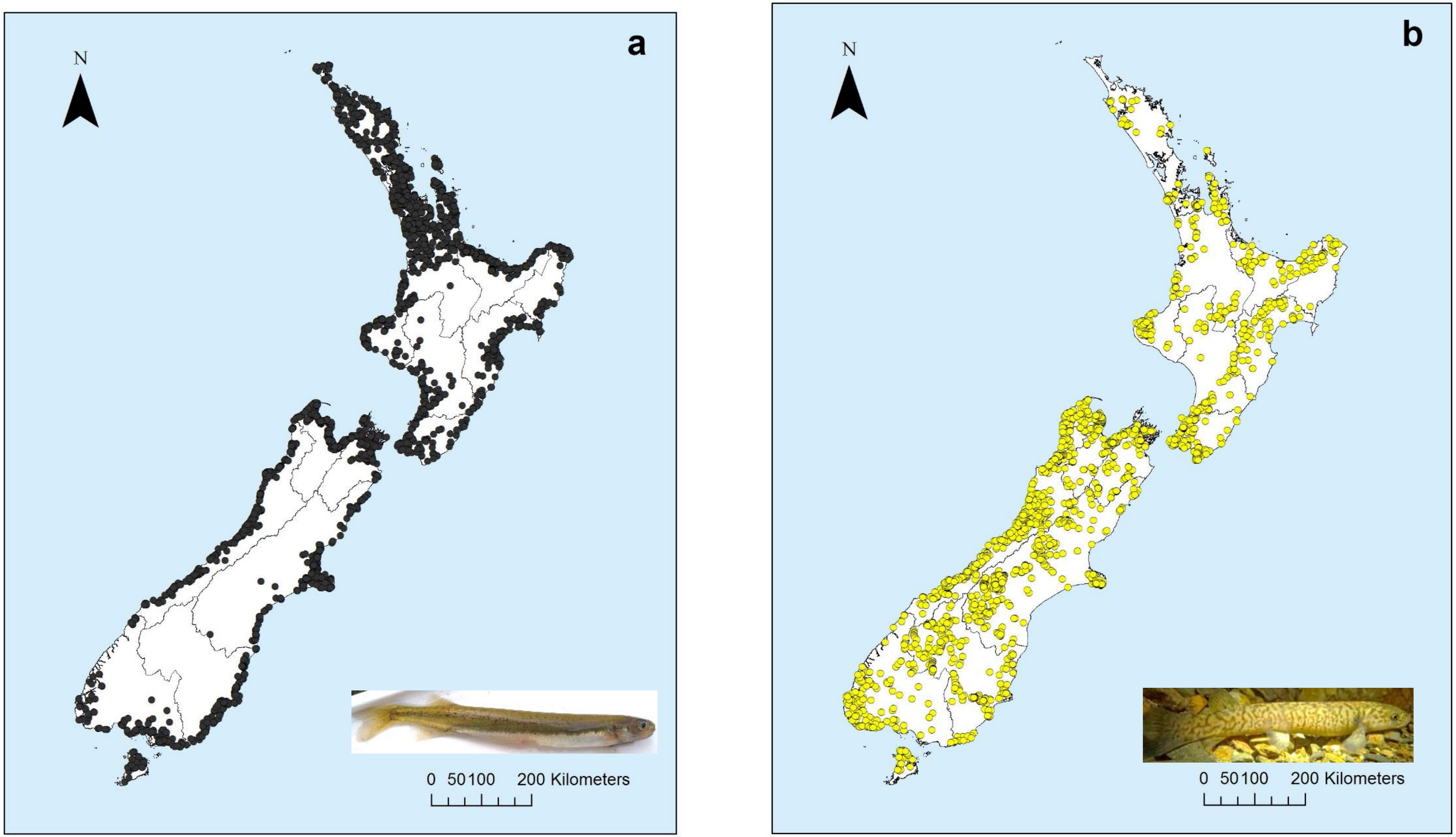


Figure 2.1 Distribution of inanga (*Galaxias maculatus*) (a), koaro *(Galaxias brevipinnis*) (b), banded kokopu (*Galaxias fasciatus*) (c), giant kokopu (*Galaxias argenteus*) (d), shortjaw kokopu (*Galaxias postvectis*) (e), and common smelt (*Retropinna retropinna*) (f) from New Zealand freshwater fish database records 1964 to 2016

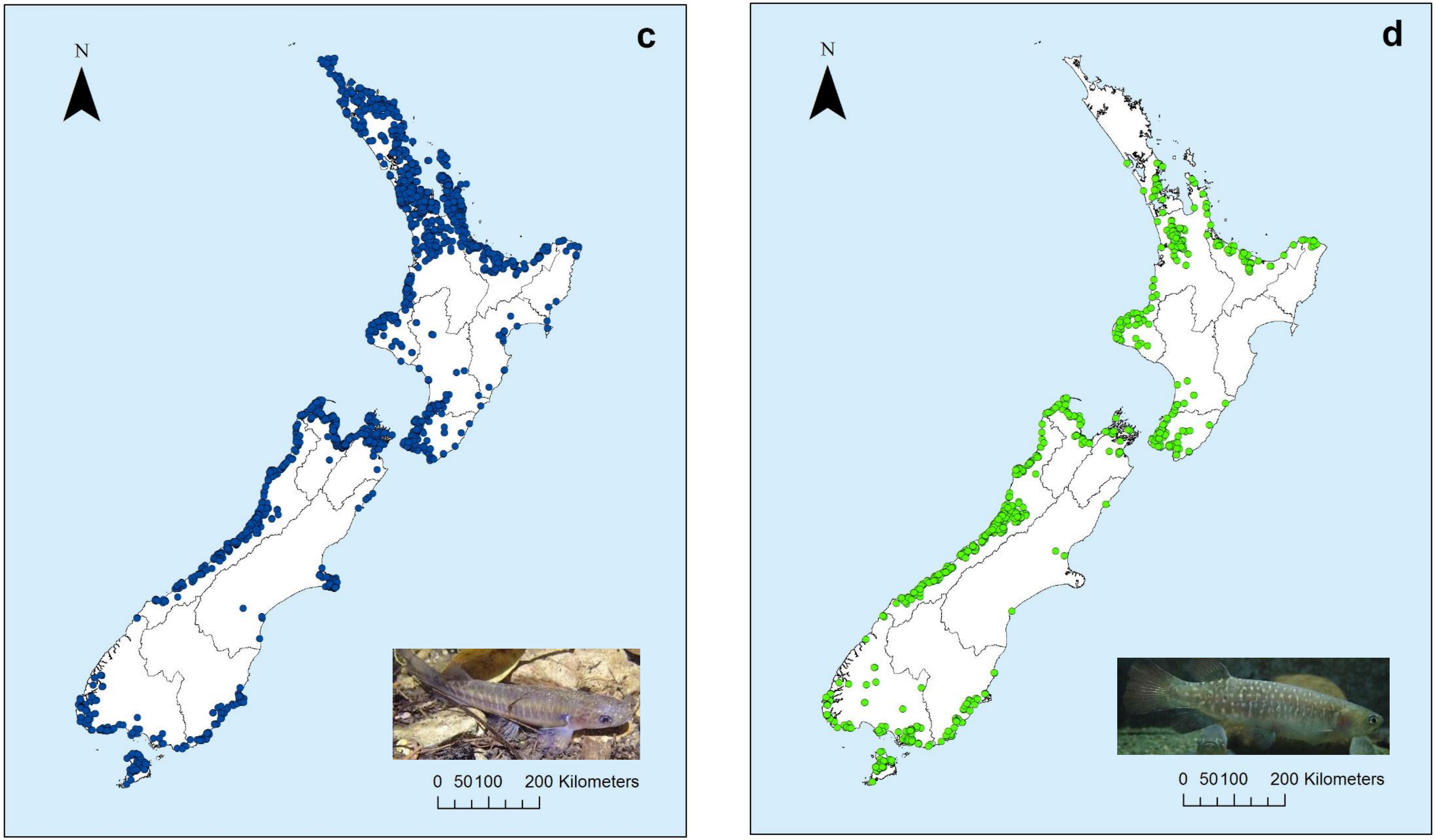


Figure 2.1 (continued) Distribution of inanga (*Galaxias maculatus*) (a), koaro *(Galaxias brevipinnis*) (b), banded kokopu (*Galaxias fasciatus*) (c), giant kokopu (*Galaxias argenteus*) (d), shortjaw kokopu (*Galaxias postvectis*) (e), and common smelt (*Retropinna retropinna*) (f) from New Zealand freshwater fish database records 1964 to 2016.

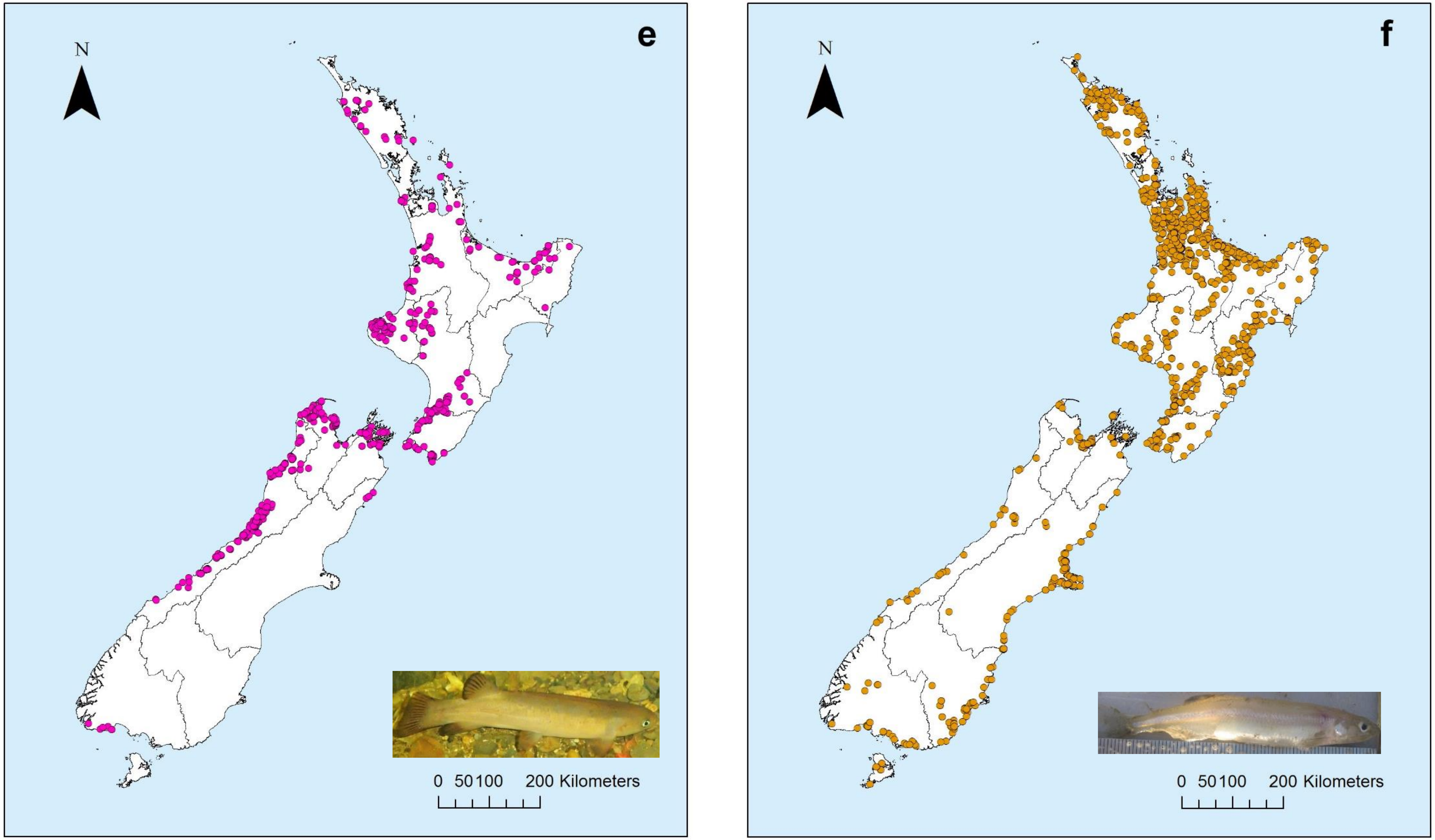


Figure 2.1 (continued) Distribution of inanga (*Galaxias maculatus*) (a), koaro *(Galaxias brevipinnis*) (b), banded kokopu (*Galaxias fasciatus*) (c), giant kokopu (*Galaxias argenteus*) (d), shortjaw kokopu (*Galaxias postvectis*) (e), and common smelt (*Retropinna retropinna*) (f) from New Zealand freshwater fish database records 1964 to 2016.

2.2 SPECIES IDENTIFICATION

Earlier composition studies have had difficulty discriminating between the five species that comprise the whitebait fishery. At the whitebait stage the fish lack the obvious distinguishing characteristics of adults. The existence of the five species has been confirmed through rearing wild caught whitebait (McDowall & Eldon, 1980), and more recently using genetic markers (Dijkstra & McDowall, 1997; Charteris & Ritchie, 2002). Morphological characteristics and pigmentation have been used to identify four of the species as whitebait (McDowall, 1999a). However, *G. postvectis* cannot be differentiated from other species and are thought to very similar to *G. brevipinnis* (McDowall & Eldon, 1980; Dijkstra & McDowall, 1997). Early identification keys created by Woods (1968) were found to be incorrect, with identification keys of *G. argenteus* based on a single fish (McDowall & Eldon, 1980).

2.2.1 How were whitebait species identified?

Whitebait were identified morphologically using keys developed by McDowall and Eldon (1980) and McDowall (1984b). Fish were identified to the lowest practical taxonomic level with a Leica MZ12S stereo microscope using morphological features (Fig. 2.2). Photos and notes were taken of any fish that could not be identified by colour, size, body proportions, fin position or other biometric characteristics.

Figure 2.2. All whitebait were examined under a microscope for identification.

2.2.2 Stages of pigmentation and separation of fish

When whitebait enter freshwater they are usually translucent and only lightly pigmented. Once in freshwater, melanophores develop on the head and body as whitebait develop into juvenile fish (Benzie, 1968; McDowall & Eldon, 1980). The duration of this development is unknown, but it is thought to occur within a few days of whitebait entering the river (McDowall & Eldon, 1980).

Pigmented fish may be present in catches at river mouths due to flood events washing fish back out to sea or from freshwater exposure in the coastal environment before migration into freshwater. This was found in a study by Allibone et al. (1999) where whitebait were caught multiple times within a river system or were found to enter rivers multiple times. This is consistent with whitebait caught directly at the mouths of rivers in this present study where a few partially developed fish were found in the catch.

Only fresh-run whitebait were used for morphological analysis to avoid any bias from post-recruitment processes. Whitebait were sorted into categories of development: clear fish, lightly pigmented, pigmented, highly pigmented, whitebait with a silver abdomen, and juvenile fish (Fig. 2.3). Whitebait beyond the highly pigmented stage were discarded from further analysis.

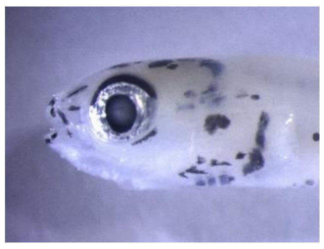
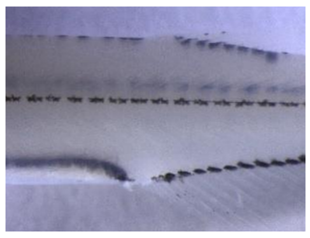
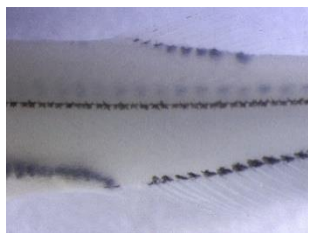
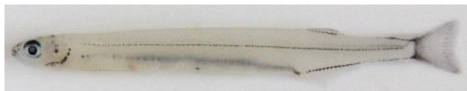
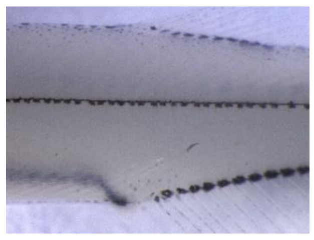
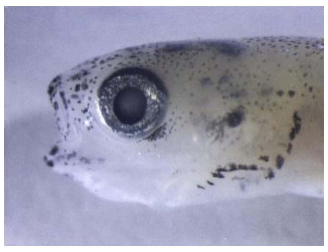
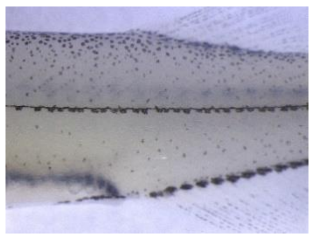
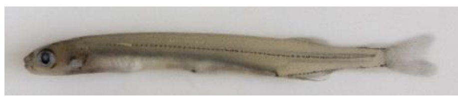
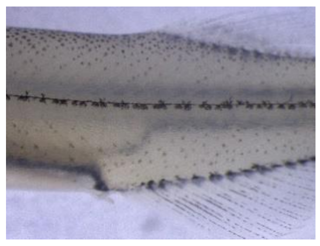
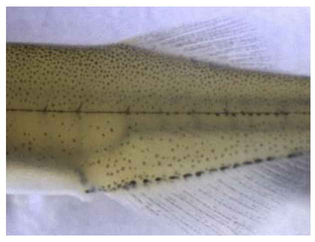
Stage	Stage of Development	Description	Photos		
			Whole Fish	Head	Anal and Dorsal Offset
1	Clear fish	Clear with some mottled melanophores characteristic of each species.			
2	Lightly pigmented	Development of a few fine melanophores along the dorsal surface of the fish.			
3	Pigmented	Development of strong speckling mainly along the dorsal surface of the fish.			
4	Highly pigmented	Development of strong melanophores all over the fish and often some internal organs. V shaped lines of melanophores develop along the myotomes.			
5	Silver abdomen	Development of a grey belly			
6	Juvenile fish	Development of strong colour and a full grey belly			

Figure 2.3. Different stages of development of inanga whitebait from clear to juvenile fish.

2.2.3 What do the five species look like?

Identification of inanga, banded kokopu and koaro whitebait was relatively simple. Differentiating giant kokopu and shortjaw kokopu proved difficult as they were found among a large number of fish with very similar characteristics.

The whitebait key published by McDowall (1984b) was useful for fish caught on the West Coast of the South Island, but this was not always the case for fish from other regions and for fish caught at either end of and outside the current whitebait season. There was considerable variation in the characteristics of whitebait from different size ranges found in the North and South Islands (Fig 2.4 to 2.9). There was also variation in whitebait of the same species found within samples (Fig. 2.10) and between months (Fig 2.11).

In some samples identification was difficult and size ranges of species played an important part in identification. When unsure about species identification, notes and photos of characteristics followed by genetic testing proved vital for accurate identification.

A distinguishing feature of some whitebait species in past studies has been colour. For example, fresh banded kokopu and giant kokopu are pale amber, koaro opaque and milky, and inanga a translucent blue/green (McDowall & Eldon, 1980). In this study, the only way to handle and process the large amount of fish was to freeze samples. This resulted in the loss of colour and meant that morphological characteristics played an even more important role for identification.

The following characteristics were useful to differentiate between species:

2.2.3.1 <u>Inanga</u>

Inanga had characteristics that made them easy to differentiate from the other four whitebait species. However, these characteristics were found to vary between individuals from the same sample. For example, a useful feature to distinguish inanga is the directly opposing insertion position of the anal and dorsal fins (Fig. 2.4), but in some fish the position was slightly offset and a combination of other characteristics was needed to identify to species level. Some inanga were translucent (especially fish caught in saltwater at river mouths) lacking strong melanophores that are normally used to identify this species. Also, size ranges varied in certain samples with large and small inanga present in the same sample (Fig. 2.10).

Distinguishing features:

- A small mouth
- Cleft of mouth reaching before or to the anterior edge of the eye
- Dorsal fin directly above the anal fin
- Mottled pigmentation (large melanophores) around the head
- Strong pigmentation along the lateral line
- Melanophores forming parallel lines along the ventral surface
- Lower and upper jaw even
- Slim body shape
- Often longer than other species in the sample

Whitebait with melanophores forming parallel lines along the ventral surface towards the head were always inanga. However, with the other four species the melanophores formed lines with a gap or split at the head (Fig. 2.4 & Fig. 2.9).

2.2.3.2 <u>Koaro</u>

The main feature that differentiated banded kokopu and koaro was length and the positions of the anal and dorsal fin (Fig. 2.5). Koaro are often considerably longer than banded kokopu and have offset anal and dorsal fins. Koaro also have a broader body shape in comparison to banded kokopu. However, like inanga, koaro could be highly variable in length and body shape. This variation was encountered both within a sample, and from fish caught between regions. For example, koaro caught in the Bay of Plenty had a slender, longer body compared to fish caught in the Buller region, which had broader body shape.

Distinguishing features:

- Shorter lower jaw
- Anal and dorsal fin offset (some fish more than others)
- Opaque white in colour
- Cleft of mouth reaching to the anterior of the eye or up to a third past
- A bulge in the parallel line of melanophores on the ventral surface
- Longer than banded kokopu
- North Island: slender body shape
- South Island: broader body shape

2.2.3.3 Banded kokopu

The smaller size range of banded kokopu in comparison to other whitebait species in the sample was very consistent and this made initial sorting easier (Fig. 2.9). However, careful examination under the microscope ensured that smaller koaro and giant kokopu were not mis-identified as banded kokopu. Several whitebait from North Island rivers had characteristics of banded kokopu, but their size and body mass were greater (Fig. 2.6). Initially these fish were thought to be large banded kokopu, but genetic analysis revealed they were giant kokopu.

Distinguishing features:

- Small mouth
- Cleft of mouth reaching to the anterior edge or ¼ past the eye
- Slim body shape in comparison to giant kokopu and koaro
- Anal and dorsal fins opposite each other
- A bulge in the parallel line of melanophores on the ventral surface
- Small size range in comparison to other species in sample

2.2.3.4 Giant kokopu

Identification of giant kokopu was difficult, particularly in North Island rivers where the known keys were not representative of giant kokopu in whitebait catches. The offset between the anal and dorsal fins of giant kokopu varied from none to a slight or distinct offset. Similarly, the distance between the anal and caudal fins varied from a small to large gap. However, if the cleft of the mouth reached halfway past the eye, or the anal fin was closely joined with the caudal fin the fish was a giant kokopu. In many cases though, particularly in the North Island, the mouth would only reach a quarter past the eye. The giant kokopu was found to be intermediate in length between banded kokopu and koaro (Fig. 2.7 & 2.9).

Distinguishing features:

- Size ranges that were often intermediate in length between banded kokopu and koaro in the same catch.
- Usually much broader in shape in comparison to koaro and banded kokopu
- North Island – mouth varying from a quarter to a third past the eye
- South Island – mouth generally a third to a halfway past the eye
- A bulge in the parallel line of melanophores on the ventral surface
- Often a short distance between the anal and caudal fin
- Intermediate in length between banded kokopu and koaro

2.2.3.5 Shortjaw kokopu

In the North Island, shortjaw whitebait were almost indistinguishable from koaro apart from a slightly larger offset of the anal and dorsal fins, and the cleft of the mouth reaching to the anterior of the eye (Fig. 2.8). In the Buller and West Coast regions, shortjaw kokopu whitebait were generally stockier than koaro with the mouth cleft only reaching before or to the anterior margin of the eye.

Distinguishing features:

- Distinct shorter lower jaw
- Mouth reaches to or before the anterior of the eye
- Short distance between the anal and caudal fins
- Similar in length with koaro but much stockier on the West Coast of the South Island.
- Offset of anal and dorsal fins (varied).
- A bulge in the parallel line of melanophores on the ventral surface

2.2.3.6 Smelt

Smelt were present in samples at varying stages of development. Adults were distinguished by the presence of scales, but juveniles had similar features to the whitebait species (Fig. 2.10).

I had difficulty in earlier samples distinguishing smelt from koaro or giant kokopu, particularly in samples from rivers in the Bay of Plenty and Waikato regions where smelt were smaller.

However, species separation became straight forward once the distinguishing characteristics had been established.

This mis-identification of smelt was apparent when whitebaiters in the Waikato region were unaware the composition of their catches consisted of almost 100% smelt. Similarly, when untrained assistants were asked to differentiate between smelt and koaro, they were not always able to do so.

Distinguishing features:

- A cucumber-like smell
- Yellow coloured melanophores along the dorsal surface
- Larger eye than whitebait species
- Cleft of mouth extends beyond the exterior of the eye
- Smaller head than koaro
- Melanophores appear as parallel lines on the ventral surface of the fish
- Adipose fin (sometimes visible)

The presence of other non-inanga species was also noted. Pictures of some of these species are shown in Figure 2.12.

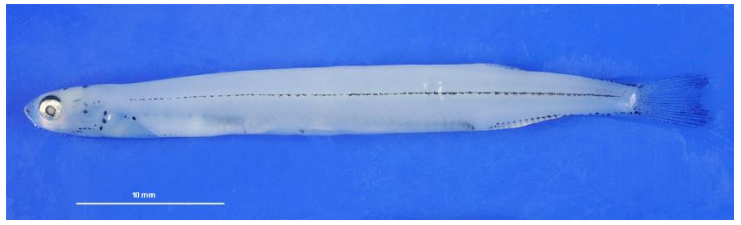
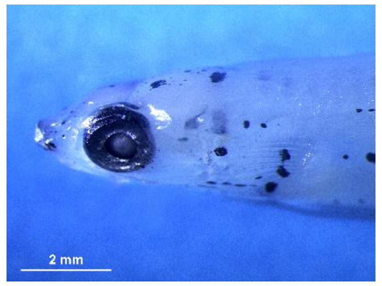
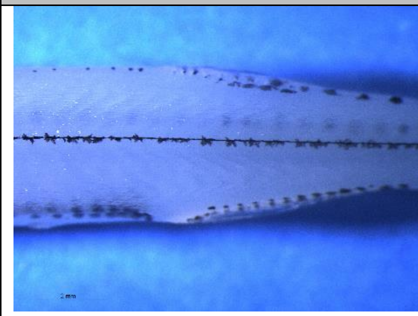
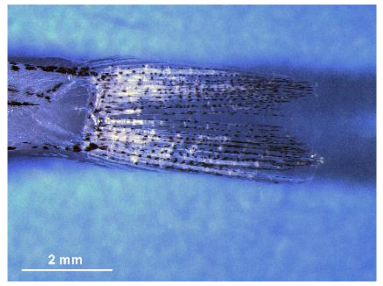
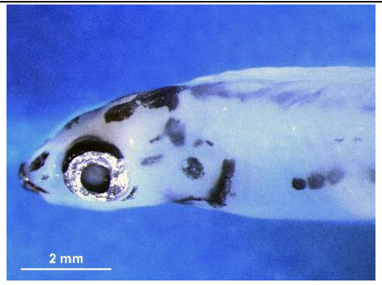
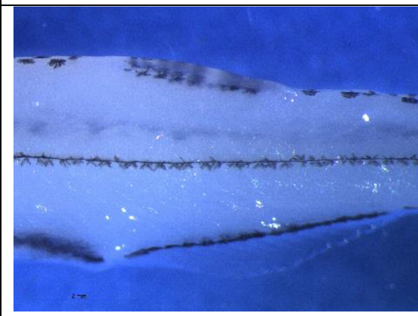
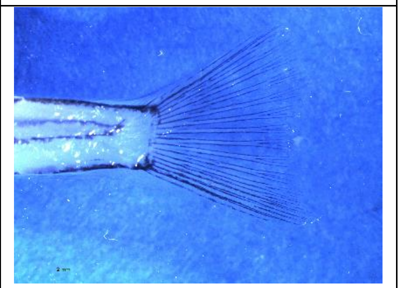
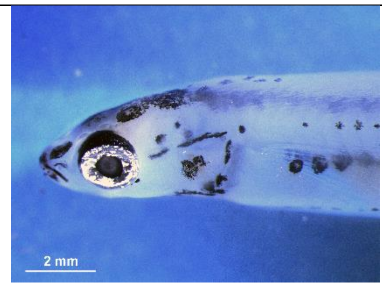
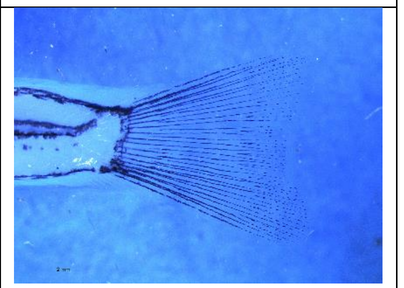
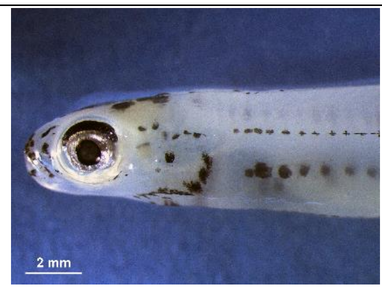
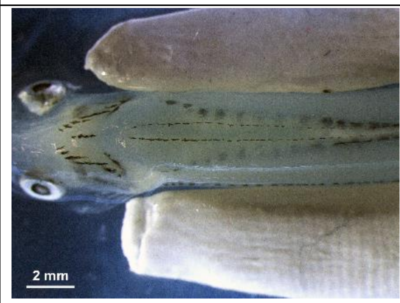
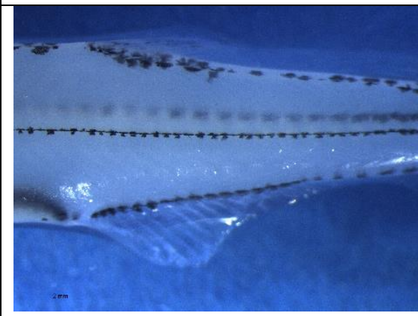
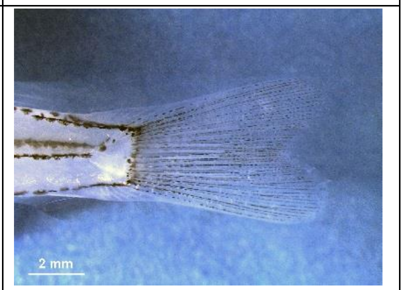
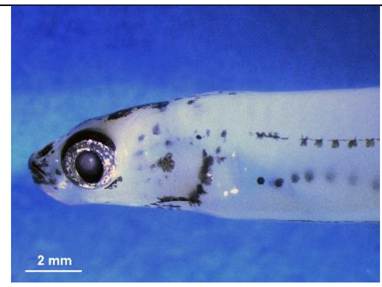
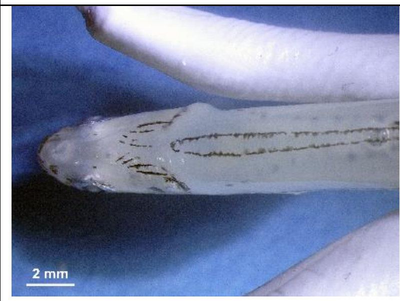
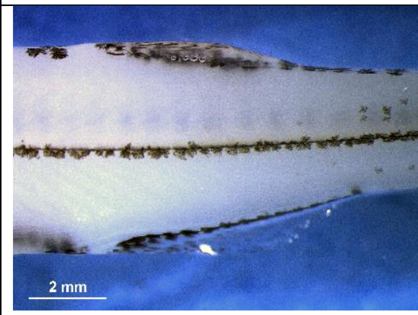
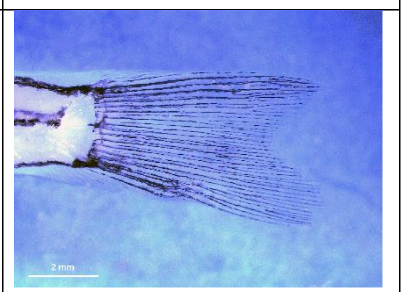
Location and date	**INANGA**				
	Whole Fish	**Head and Pectoral Fin**	**Anterior Region (Ventral)**	**Dorsal and Anal Fin**	**Tail**
Waikato Region Waikato River 4 November 2016 					
Bay of Plenty Region Kaituna River 2 October 2016 					
Canterbury Region Waimakariri River 17 November 2016 					
Westland Region Waiatoto River 2 October 2016 					
Southland Region Waiau River 14 October 2016 					

Figure 2.4. Inanga *Galaxias maculatus* from 5 rivers throughout New Zealand showing characteristics used for identification.

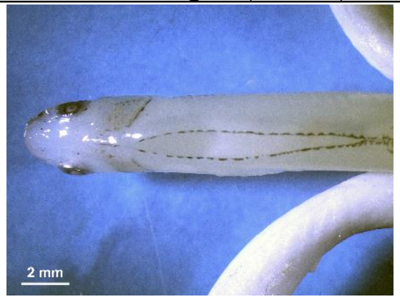
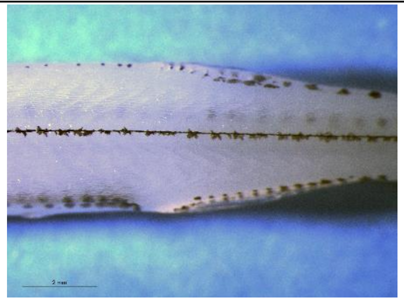
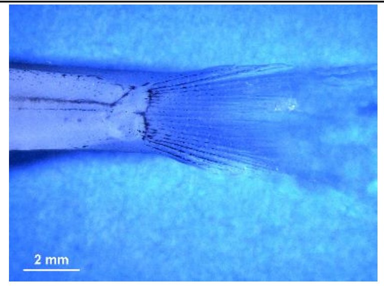
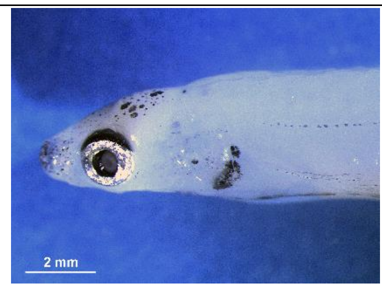
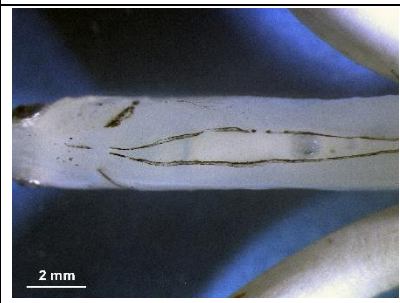
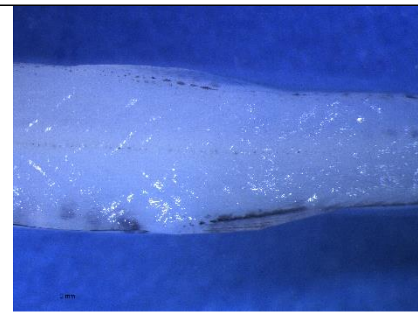
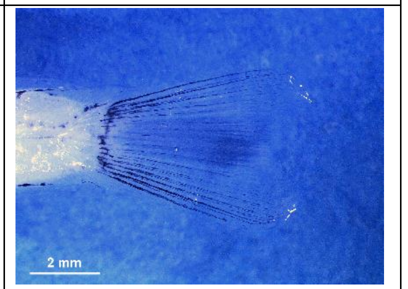
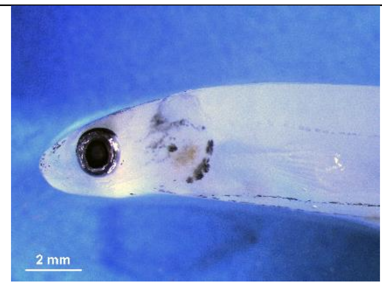
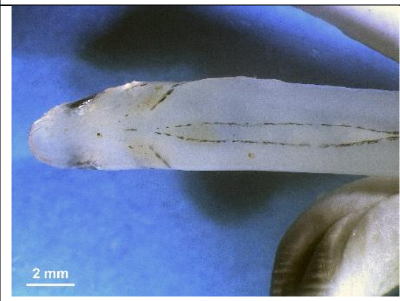
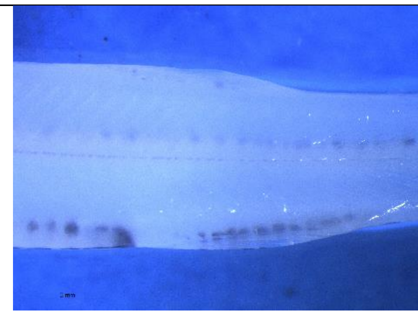
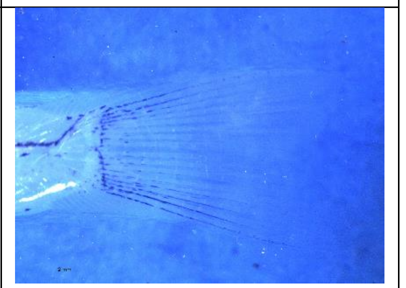
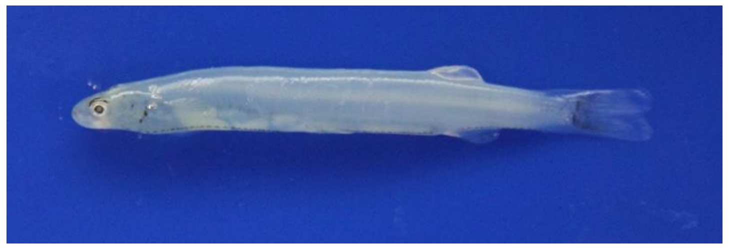
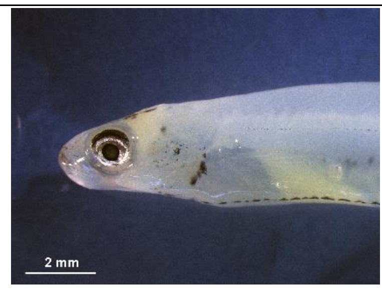
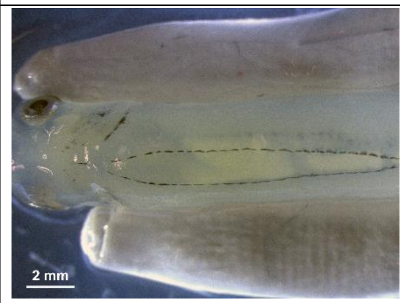
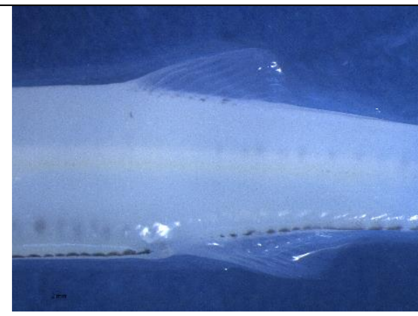
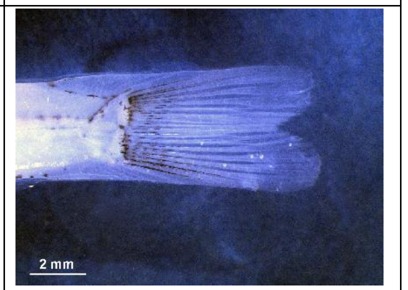
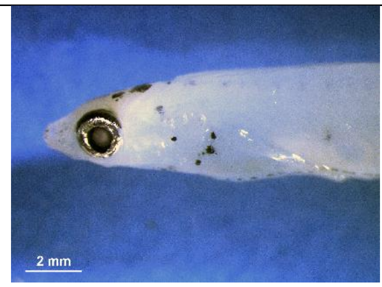
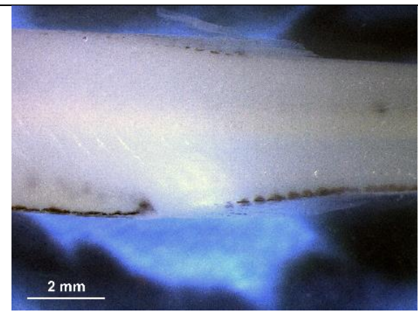
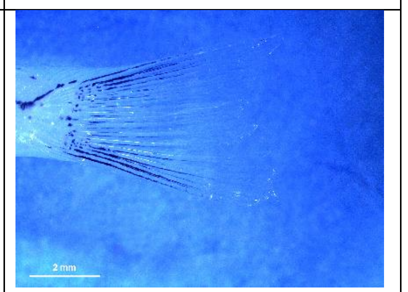
Location and date	**KOARO**				
	Whole Fish	**Head and Pectoral Fin**	**Anterior Region (Ventral)**	**Dorsal and Anal Fin**	**Tail**
Waikato Region Waikato River 4 November 2016 					
Bay of Plenty Region Kaituna River 2 October 2016 					
Canterbury Region Waimakariri River 17 November 2016 					
Westland Region Waiatoto River 2 October 2016 					
Southland Region Waiau River 14 October 2016 					

Figure 2.5. Koaro *Galaxias brevipinnis.* from 5 rivers throughout New Zealand showing characteristics used for identification

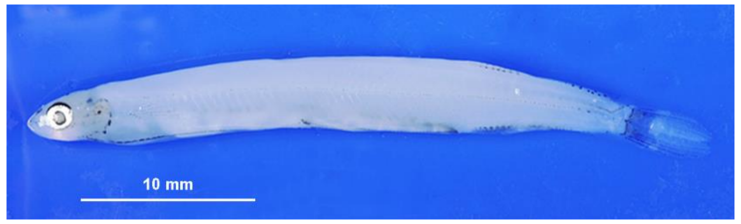
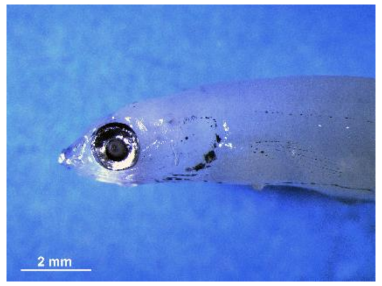
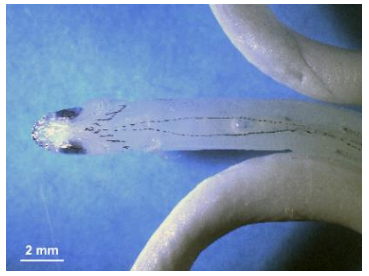
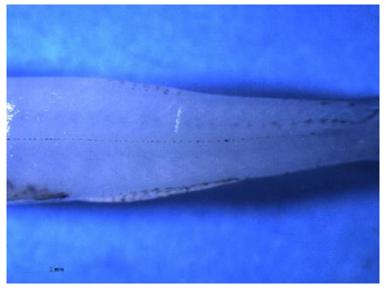
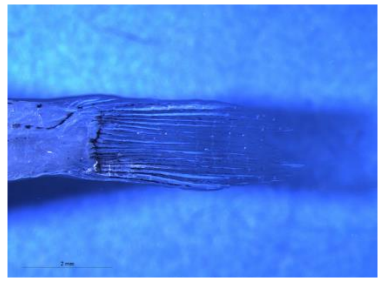
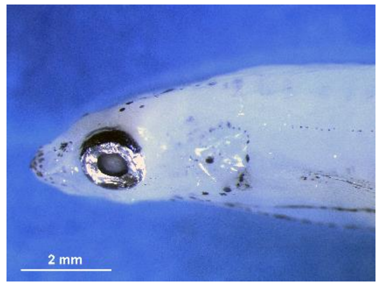
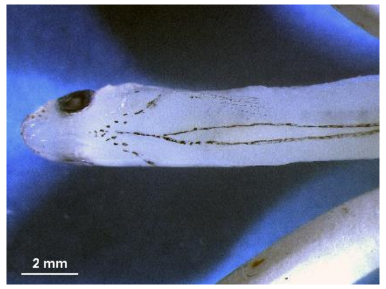
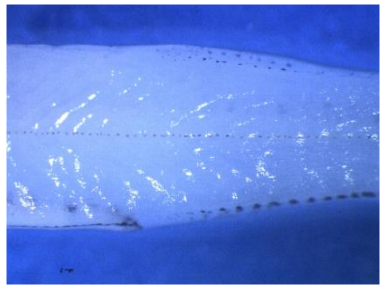
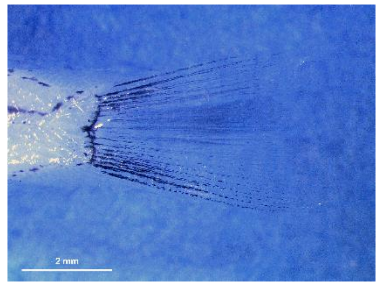
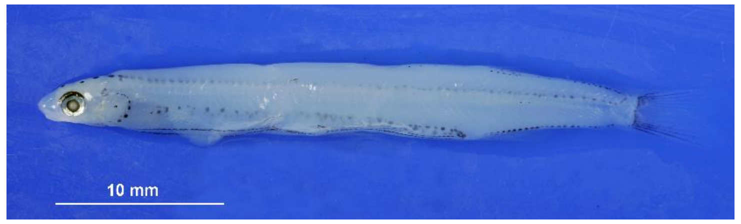
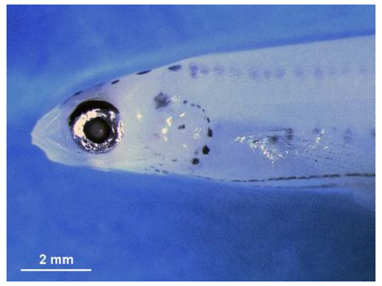
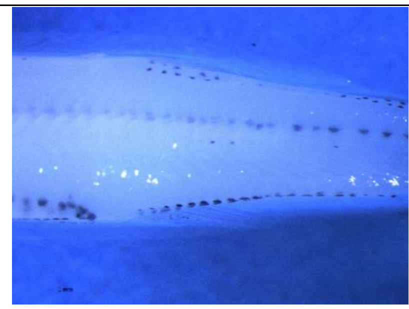
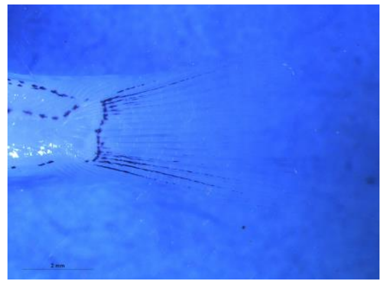
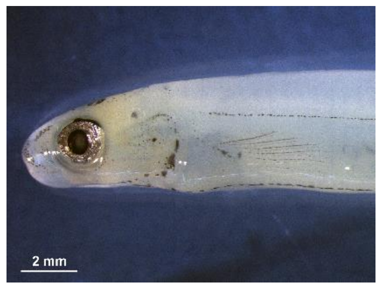
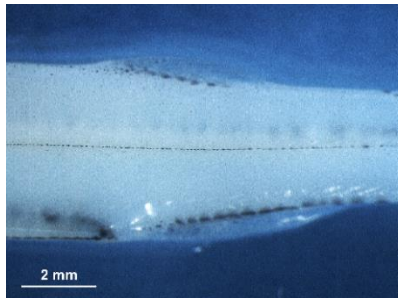
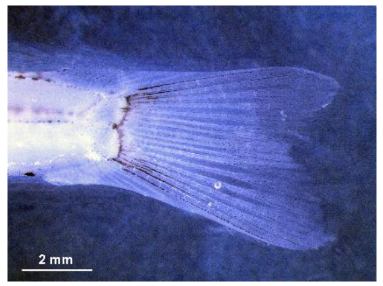
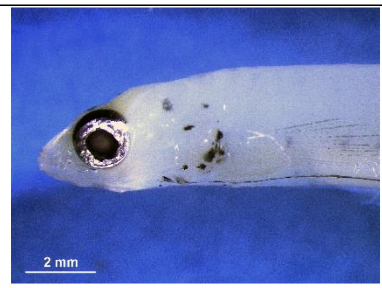
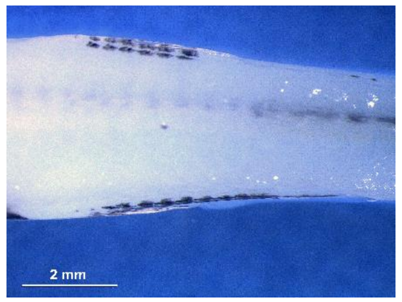
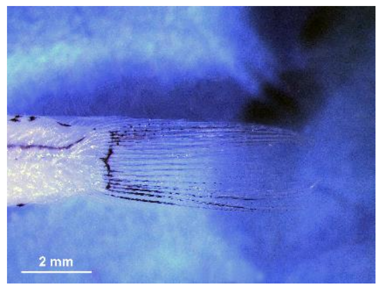
Location and date	**BANDED KOKOPU**				
	Whole Fish	**Head and Pectoral Fin**	**Anterior Region (Ventral)**	**Dorsal and Anal Fin**	**Tail**
Waikato Region Waikato River 4 November 2016 					
Bay of Plenty Region Kaituna River 2 October 2016 					
Canterbury Region Waimakariri River 17 November 2016 					
Westland Region Waiatoto River 2 October 2016 					
Southland Region Waiau River 14 October 2016 					

Figure 2.6. Banded kokopu *Galaxias fasciatus.* from 5 rivers throughout New Zealand showing characteristics used for identification

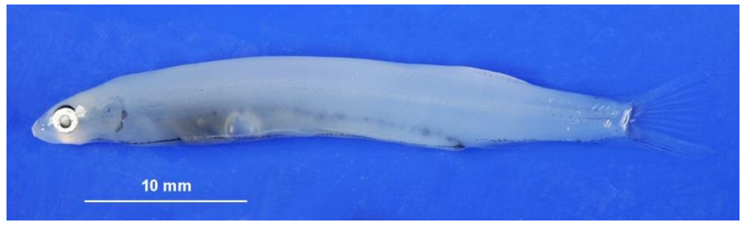
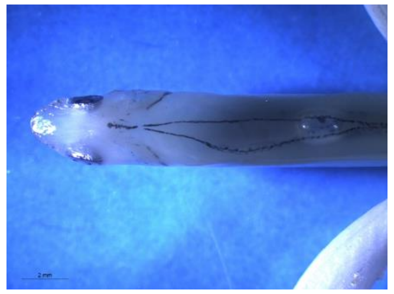
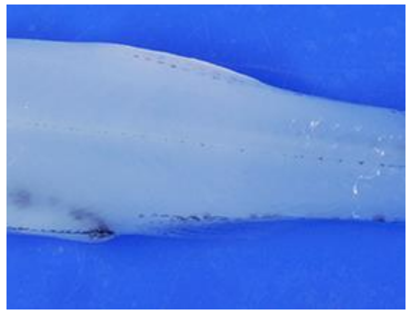
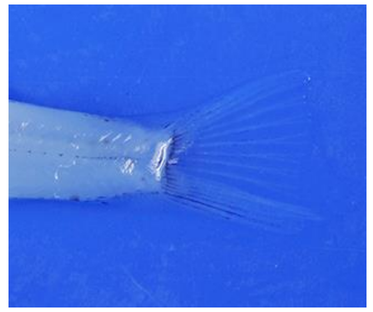
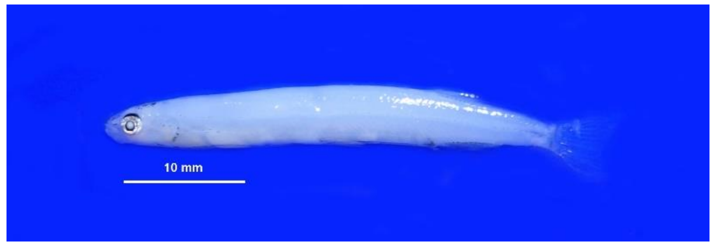
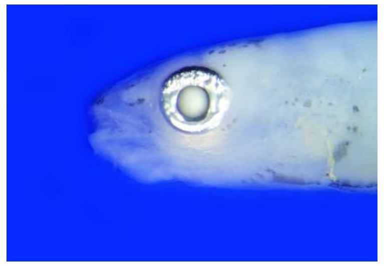
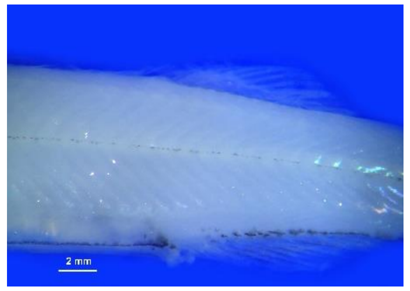
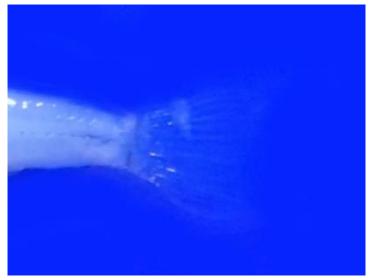
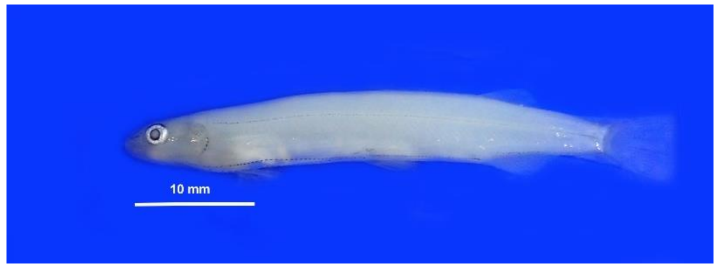
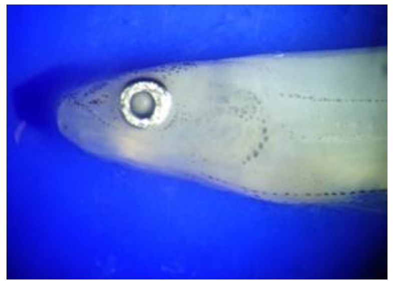
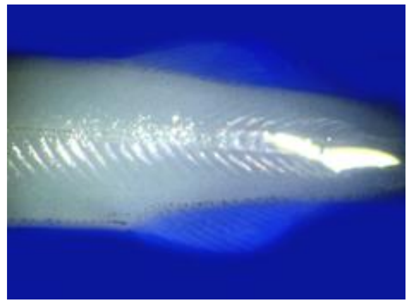
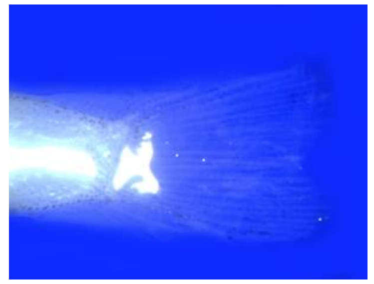
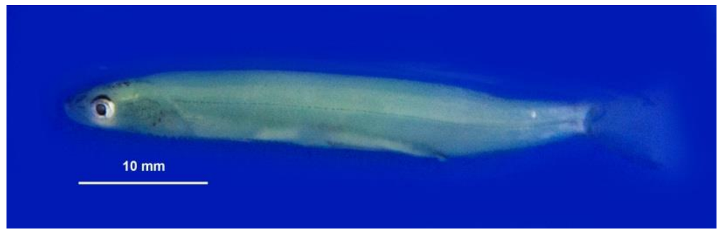
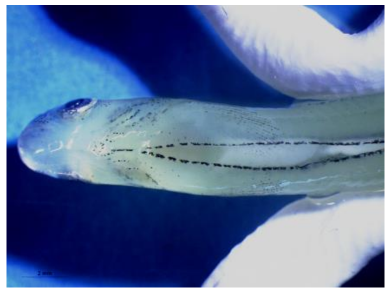
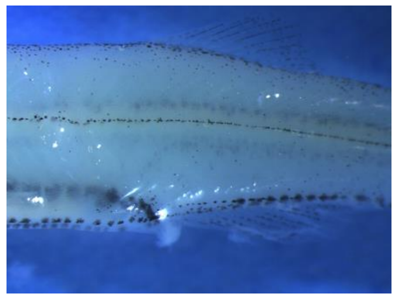
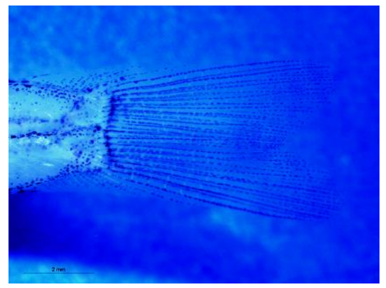
Location and date	GIANT KOKOPU				
	Whole Fish	Head and Pectoral Fin	Anterior Region (Ventral)	Dorsal and Anal Fin	Tail
Waikato Waikato River 4 November 2016 					
Waikato Mokau River 18 November 2015 			NA		
Tasman-Nelson Takaka River 30 November 2015 					
Westland Region Waiatoto River 7 November 2016 					

Figure 2.7. Giant kokopu *Galaxias argenteus* from 4 rivers throughout New Zealand showing characteristics used for identification.

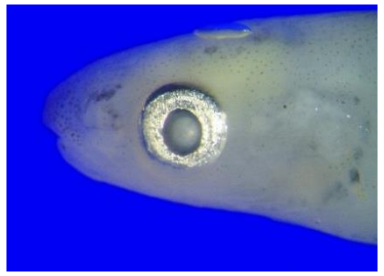
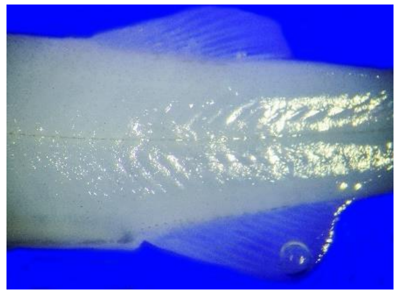
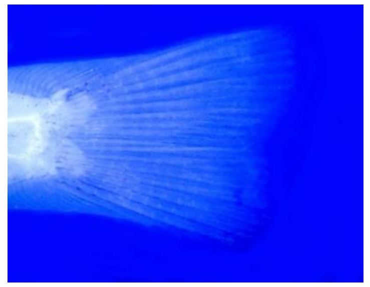
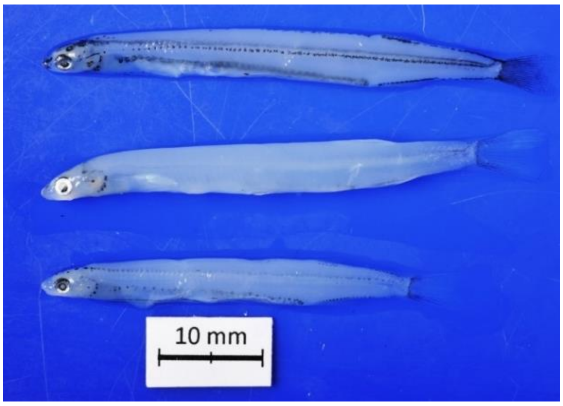
Location and date	**SHORTJAW KOKOPU**				
	Whole Fish	**Head and Pectoral Fin**	**Anterior Region (Ventral)**	**Dorsal and Anal Fin**	**Tail**
Buller Region Buller River 2 November 2015 			NA		
Westland Region Waimea Creek 7 November 2015 			NA		

Figure 2.8: Shortjaw kokopu *Galaxias postvectis.* from 2 rivers on the West Coast of the South Island showing characteristics used for identification

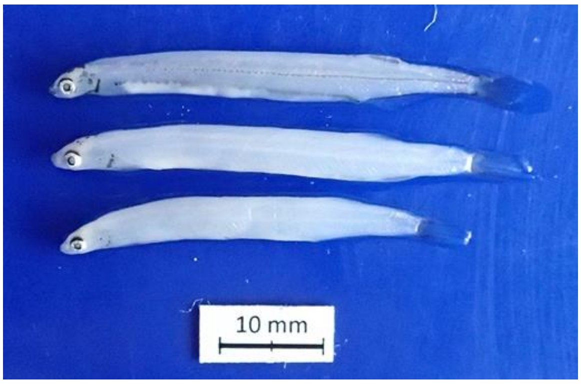
Variation in size ranges of species in the same sample

Waikato River (Waikato) 4 November 2016
Inanga (top), banded kokopu (middle), giant kokopu (bottom)

Waimakariri River (Canterbury) 17 November 2016
Inanga (top), koaro (middle), banded kokopu (bottom)



Kaituna River (Bay of Plenty) 09 September 2016
Inanga (top), koaro (middle), banded kokopu (bottom)



Waiatoto River (Westland) 17 November 2016
Inanga (top), banded kokopu (top middle), koaro (bottom middle) giant kokopu (bottom)

Waiatoto River, Westland 1 November 2016
Inanga (top), koaro (middle), banded kokopu (bottom)
Variation in melanophore split

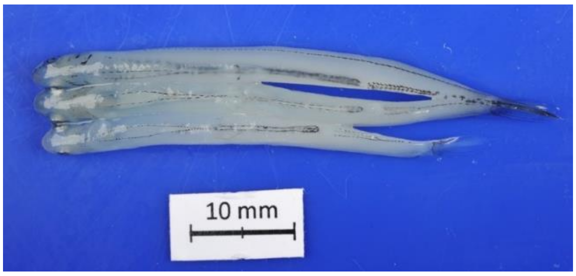


Figure 2.9. Variation in size ranges between species in 6 whitebait samples.

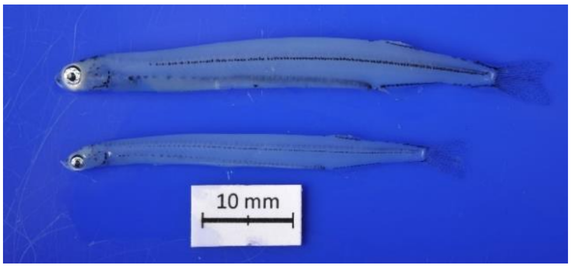
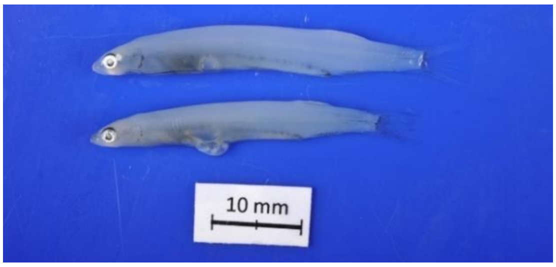
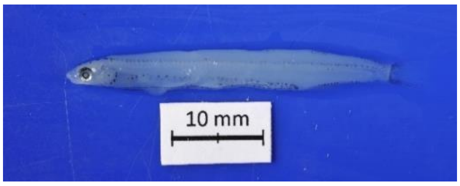
<table>
<tr><th colspan="2">Variation in species size ranges within the same sample</th></tr>
<tr><td>Waimakariri River (Canterbury) Inanga
16 December 2016: 54.5mm (top), 44.8mm (bottom)</td><td>Waikato River (Waikato) Giant kokopu
4 November 2016: 42.4mm (top), 36.7mm (bottom)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Waikato River (Waikato) Common Smelt
13 November 2016, – 54.5mm (top fish) 44.8mm (bottom fish)</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Figure 2.10. Variation seen in total length of inanga (top left), giant kokopu (top right) and smelt (bottom) within the same sample.

<table>
<tr><th colspan="2">Variation in species size ranges between months</th></tr>
<tr><td>Waimakariri River (Canterbury) Banded kokopu
17 November 2016 – 41.5mm (top)
16 December 2016 – 37.0mm (bottom)</td><td>Waikato River (Waikato) Banded kokopu
08 September 2016 – 40.8mm (top),
4 November 2016 – 39.7mm (bottom)</td></tr>
<tr><td>

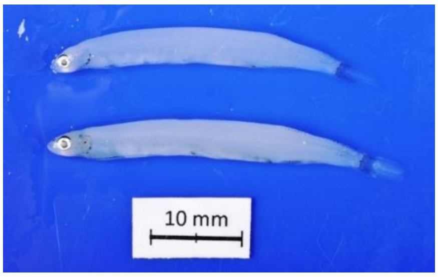

</td><td>
</td></tr>
</table>

Figure 2.11 Variation seen in total length of banded kokopu from Waimakariri River (left) and Waikato River (right) in samples between months

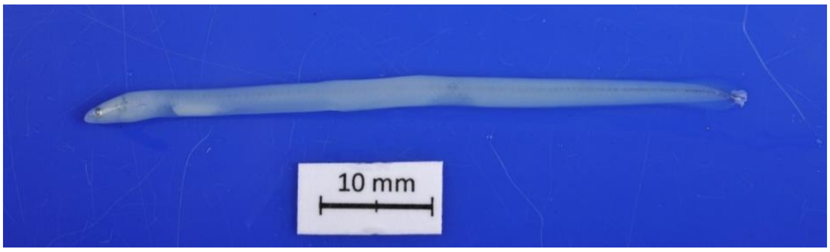
<table>
<tr><th colspan="2">Other species in catches</th></tr>
<tr><td>Paratya Shrimp
14 November 2016, Waikato River (Waikato)</td><td>Juvenile bully
28 October 2016, Waiau River (Southland)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Glass Eel
11 September 2016, Waimakariri River (Canterbury)</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

Figure 2.12. Non-galaxiid species caught in whitebait samples: paratya shrimp (top left), juvenile bully (top right), and glass eel (bottom).

2.2.4 Genetic confirmation of species identification

Previous studies have developed genetic markers to confirm species identification of the five whitebait species (Dijkstra & McDowall, 1997; Charteris & Ritchie, 2002). After fish were identified to the lowest practical level morphologically, whitebait were preserved in vials with 70% ethanol. A sample of 51 whitebait of known species identity, whitebait where there was uncertainty, and unidentified whitebait were tested genetically to confirm species identification. This testing was undertaken by the Genetic Analysis Service, Department of Anatomy, University of Otago. Blind samples of caudal fin clips stored in vials of 70% ethanol were sent for testing. After gaining results from the first batch of fish, and confirming species characteristics and regional differences, another 30 fish were tested (see Appendix 4).

DNA Extraction

DNA was extracted from the caudal fin clips (1mm x 2mm) leaving the specimens intact for further morphological clarification. DNA was extracted using Chelex 100 resin (BioRad) following a modification of Casquet et al. (2012). Caudal fin tissue was placed into individual 1.5ml tubes containing 400µl of 5% Chelex and 40mg proteinase K. Following an overnight incubation, tubes were heated to 90°C for 10 minutes then centrifuged at ~20,000 x g for 10 minutes.

PCR Amplification and sequencing

Approximately 1200bp of mitochondrial cytochrome b was amplified using primers situated in the flanking tRNAs; cytb-glu and cytb-thr (Waters et al., 2001). PCRs contained 0.5µM each primer and 1 x MyFi Mix (Bioline) in a total volume of 10µl and were cycled in an Eppendorf Mastercycler Pro S thermocycler: 94°C for 120 s, followed by 35 cycles of 94°C for 30 s, 47°C for 30 s, 72°C for 60 s, with a final extension of 72°C for 240 s.

Two microliters of amplified DNA was visualised on a 1% agarose gel containing SYBR safe (Thermo Fisher) using a blue LED transilluminator (UVI). The remaining DNA was purified using a MEGA quick-spin total fragment DNA purification kit (iNtRON) and quantified using a Nanodrop ND-1000 spectrophotometer (Thermo Fisher). Purified DNA was sequenced using primer cytb-glu on an ABI 3730xl DNA Analyser (Genetic Analysis Service, Department of Anatomy, University of Otago), producing up to 930bp of useable sequence after editing.

Species identification

Species identification was diagnosed using BLAST searches of the NCBI GenBank database (Altschul et al., 1990), and confirmed by aligning the sequences to a large dataset containing reference sequences (TK unpublished data) and subsequent Neighbour-Joining tree building. Due to very limited sequence information in GenBank for *Galaxias argenteus*, close matches to this species were found only when a shortened fragment of the unknown DNA sequences was used.

2.2.5 Were the morphological identifications correct?

Genetic species identifications occurred after the majority of whitebait samples had been processed. In the first batch of tested fish, six genetic species identifications differed from morphological identifications. After the first batch of genetic species identifications, uncertainty associated with regional differences was resolved. Subsequently, all 30 morphological identifications of the second batch of fish were confirmed as being correct by the genetic species identification.

In the first batch of genetic species identification, all but 1 of 15 whitebait of 'known' species (inanga, koaro and banded kokopu) from morphological identifications were correct. A single whitebait from the Whakatane River (Bay of Plenty) that was thought to be a koaro was actually a shortjaw kokopu. In the second batch of genetic species identification another koaro from the same sample was tested and was confirmed as a koaro. This confirms the difficulties, as highlighted by McDowall and Eldon (1980), of distinguishing between shortjaw kokopu and koaro whitebait.

There was uncertainty with some species identifications due to variability between regions. Several fish from North Island rivers were thought to be either large banded kokopu or giant kokopu. Of seven such fish, five were found to be giant kokopu after genetic species identification. Once these species identifications had been confirmed in the first batch of samples this provided confirmation for the lack of size variability of banded kokopu and showed that at times the mouths of giant kokopu reach only ¼ past the eye particularly in North Island rivers.

From the first batch of testing of 17 fish that were thought to be giant kokopu, 15 were confirmed with genetic species identification. With the second set of testing, and with a better understanding of regional variability, all nine fish identified morphologically as giant kokopu were confirmed with genetic species identification.

Several banded kokopu and inanga were found to have slightly offset anal and dorsal fins; a characteristic that is not typical of these species. For example, several whitebait from the Hoteo River (Auckland) and the Wentworth River (Coromandel) that were genetically identified as banded kokopu had distinctly offset anal and dorsal fins. This is very uncommon and demonstrates the importance of using combinations of morphological characteristics for species identification.

Ten whitebait that had characteristics slightly different to other koaro or that had features similar to the existing identification key for shortjaw kokopu were submitted for genetic species identification. Four of these fish from four regions in the North and South Islands were confirmed as shortjaw kokopu. Inaccuracies were likely with shortjaw kokopu due to the difficulty of distinguishing them from koaro. Thus, the only real way to presently confirm species identification was through genetic testing.

Genetic confirmation of species identification provided assurances that regional differences were resolved and species were accurately identified. In Appendix 4 I have included notes about justification for species identifications and river, regions and dates to assist with future identifications of whitebait.

CHAPTER THREE: SPATIAL VARIATION IN THE SPECIES COMPOSITION AND MORPHOLOGY OF THE WHITEBAIT FISHERY

Summary

- Inanga made up the highest proportion of whitebait in samples from across New Zealand.
- Species composition varied among and within regions throughout New Zealand.
- Buller had the highest within-region variability in species composition.
- There were variations in size among whitebait species.
- The size of whitebait at migration varied among and within regions.
- Whitebait at higher latitudes were longer than those at lower latitudes.
- Non-whitebait species observed in samples included smelt (which were particularly abundant in some rivers at certain times of the year), freshwater shrimp, glass eels, adult eels, juvenile and adult bullies, yellow-eyed mullet, and lamprey.

3.1 Introduction

This chapter examines spatial variability in species composition and morphology of the whitebait fishery across New Zealand at different spatial scales. Understanding spatial variability in species composition and morphology is important as the fishery extends around the entire coastline of New Zealand. Furthermore, there is extensive variability in oceanic conditions around New Zealand (Ross, 2009). Although this is known to greatly affect organisms in the marine environment (O'Connor et al., 2007), little is known about how this affects developing larvae of the five whitebait species. Examining the species composition and morphology of the whitebait catch within and between regions will help to define this variability, and will provide insights into regional differences in the timing of migration and dispersal.

In all composition studies to date, inanga (*Galaxias maculatus)* made up the largest proportion of the whitebait catch, but in some rivers, and at certain times of the year, koaro (*G. brevipinnis)* and banded kokopu (*G. fasciatus)* also made substantial contributions (McDowall, 1965; Rowe et al., 1992). Spatially, although still dominated by inanga, the West Coast of the South Island was shown to have higher proportions of non-inanga species compared to the East Coast (McDowall, 1965). Information about the species composition of the whitebait catch is not available for other regions of New Zealand, but there is likely to be significant variability given the vast regional differences in river type, forest cover in catchments and the presence of adults (McDowall & Eldon, 1980; Rowe et al., 1992; Richardson et al., 1994; Boubée et al., 1997; Baker & Montgomery, 2001; Richardson et al., 2001). Furthermore, given the strong association of non-inanga adults with forested habitats (McDowall, 2000; Goodman, 2002; Baker & Smith, 2007), these species may be particularly abundant on the West Coast of both islands because of the higher proportion of forest cover compared to East Coast regions.

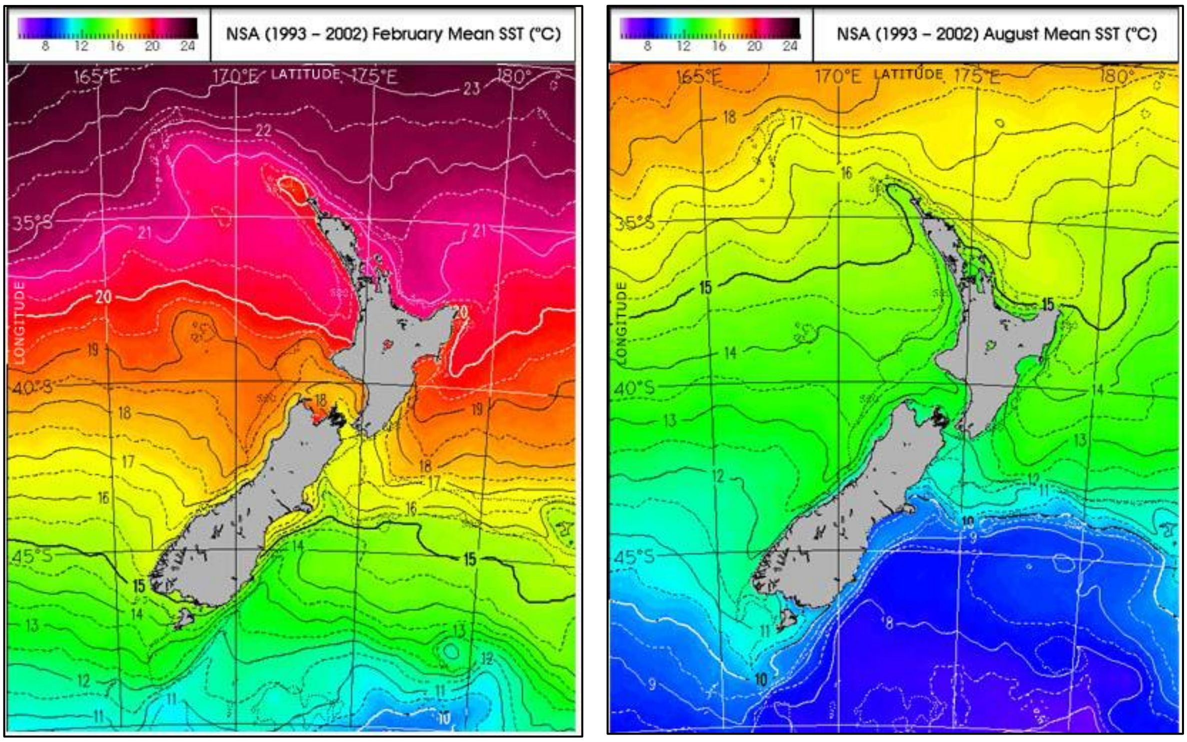


Figure 3.1. Mean sea surface temperatures around New Zealand during February and August in the period 1993-2002 (Stevens & Chiswell, 2006).

There is very limited information about variation in whitebait morphology, because only two of the studies examining the species composition of the whitebait catch collected morphological measurements (i.e., McDowall & Eldon, 1980; Stancliff et al., 1988), but not across multiple regions. However, Rowe and Kelly (2009) and (McDowall, 1968) completed spatial studies of inanga length and found that North Island whitebait were smaller than those caught in the South Island. Although clear differences were found between the islands, only a single river was sampled in each island so this was not conclusive.

Fish that develop in warmer water grow faster and are smaller than fish that develop in cooler water (Barlow, 1961). Therefore, it is expected that the length, weight and body depth (distance between the anterior insertion of the anal and dorsal fins) of migrating whitebait will vary between regions as marine larvae are likely to have experienced differing growth during their planktonic phase. Whitebait are likely to be particularly large on the West Coast of the South Island because of cool sea surface temperatures and high productivity (Schiel, 2004; Fig. 3.1). Moreover, with complex oceanic currents (Chiswell et al., 2015; Fig. 3.2) there is likely to be intermixing of whitebait in some regions (for example around Cook Strait with the Westland, D'Urville, and Southland currents meeting) which could result in morphological variability.

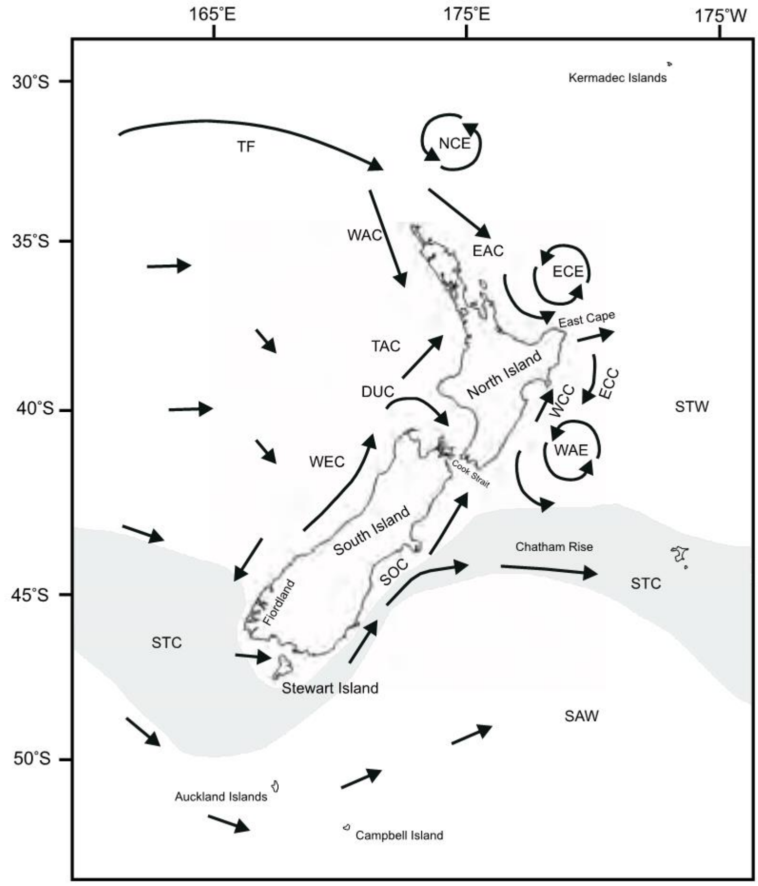


Figure 3.2. New Zealand's major coastal current systems and boundaries between water masses. DUC, D'Urville current; EAC, East Auckland current; ECC, East Cape current; ECE, East Cape Eddy; NCE, North Cape Eddy; SOC, Southland current; SAW, Subantarctic water; STC, Subtropical Convergence; STW, Subtropical water; TAC, Tasman current; TF, Tasman Front; WAC, West Auckland current; WAE, Wairarapa Eddy; WCC, Wairarapa coastal current; WEC, Westland current (Ross, 2009).

Little is known about the marine dispersal of whitebait and metapopulation dynamics. While species such as salmon return to their natal rivers (Keefer & Caudill, 2014), this is unlikely for whitebait (Hickford & Schiel, 2016). Inanga (New Zealand, Australia and South America) (Waters et al., 2000), and koaro (Australia) (O'Connor & Koehn, 1998) are geographically widespread, but banded kokopu, giant kokopu and shortjaw kokopu are endemic (McDowall, 2000). The lack of discernible population structure of inanga within New Zealand and overseas suggests the possibility of considerable marine dispersal and connectivity between populations (leaky borders between populations) (Redlich, 2012), but otolith studies indicate the presence of distinct populations with inter-regional movements within the West Coast and East Coasts of the South Island (Hickford & Schiel, 2016). This study may give further indications on the distance whitebait species disperse by examining whitebait over a large geographical area, particularly of non-inanga species which little is known. If regional differences are seen in species composition and morphology this may suggest limited dispersal while similarities between regions seen throughout New Zealand suggests greater dispersal and mixing of populations. Furthermore, variability in species composition within rivers in regions may suggest whitebait are being retained in some locations or are selecting rivers based on particular characteristics.

In addition to whitebait, many other fish species are collected in whitebait catches. Smelt can make up high proportions of samples in some rivers at particular times of the year (McDowall, 1965; Ward et al., 2005). Smelt are likely to be observed throughout New Zealand because of their widespread distribution (McDowall, 2000); (Fig. 2.1f). Other species such as bullies, shrimps, and eels are likely to be present in samples because of their diadromous life cycle and movement through the habitats where whitebaiters fish (McDowall, 1965).

The following questions were addressed in this chapter:

1. *What are the species composition, length, body depth and condition of whitebait entering rivers in the North and South Islands of New Zealand?*
2. *Do any environmental variables influence the species composition of whitebait entering rivers and streams?*
3. *Are there small-scale spatial differences in the species composition and morphology of the whitebait catch regionally and between rivers?*
4. *Which other species are found in the whitebait catch?*

3.2 Methodology

See Chapter 1 for details of the methods used to sample whitebait and the rivers used for the spatial study.

3.2.1 Laboratory Work

The procedures used to identify whitebait species are detailed in Chapter 2. After species identification and sorting into different levels of pigmentation, three morphological measurements were taken from each fish species: total length, body depth and wet weight.

3.2.1.1 Sub-sampling

Defrosted whitebait were grouped by species in blue plastic sorting trays. (Fig. 3.3). The two largest and two smallest individuals of each species were selected to include the maximum size range of the whitebait present. An additional 36 whitebait were selected randomly to give a subsample of 40 individual fish. Only fresh-run/clear whitebait (Fig 2.2; whitebait migrating directly from the sea for the first time) were used for morphological analysis to avoid any bias from post-recruitment processes. Several authors have found that fish start developing pigmentation shortly after they enter the freshwater environment (McDowall & Eldon, 1980). However, in samples with fewer than 40 fish, all whitebait were measured and their level of pigmentation was noted. Whitebait that had developed a silvery lining on their abdominal cavity (from guanine deposition) were excluded from sub-samples.

Figure 3.3. Whitebait were placed into groups of ten on blue trays for counting and sorting.

3.2.1.2 Measuring Body Depth

Initial trials showed that the most consistent method to determine body depth was to leave the whitebait lying in 5mm of water in the tray. A Leica MZ125 stereo microscope fitted with a calibrated graticule in one of the eyepieces was used to measure body depth - the distance between the anterior insertion of the dorsal fin and the anterior insertion of the anal fin (± 0.1 mm) at 16x magnification (Figure 3.4).

(a) Banded kokopu (*G. fasciatus*)	(b) Koaro (*G. brevipinnis*)

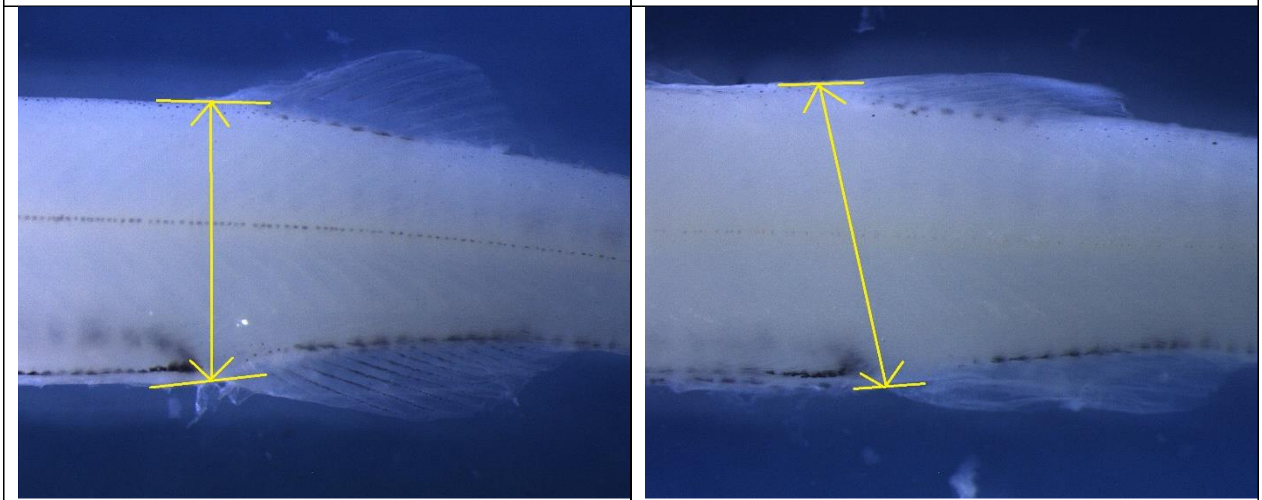


Figure 3.4. Measuring body depth (± 0.1 mm) in whitebait with opposing (banded kokopu; left) and offset (koaro; right) anal and dorsal fins.

3.2.1.3 Measuring Total Length

Following body depth measurements, whitebait were transferred onto a paper towel to absorb excess water and then placed on a stainless steel bench. Fish were straightened without stretching their body. Total lengths were measured with electronic callipers (± 0.01 mm) (Fig. 3.5a).

3.2.1.4 Measuring Wet Weight

After length measurements, whitebait were transferred back onto a dry paper towel and lightly patted dry. Whitebait were weighed on an electronic balance (± 0.001 grams) (Fig. 3.5b). The whitebait were then transferred into 70% ethanol in a 7ml plastic vial along with a waterproof label (Fig. 3.5c).

Figure 3.5. Measuring the total length (± 0.01 mm) of an inanga whitebait with electronic callipers (top), measuring the wet weight (± 0.001 grams) of an inanga whitebait with electronic scales (bottom left), and storing whitebait in plastic vials with 70% ethanol (bottom right).

3.2.1.5 <u>Conversion factor for fresh to frozen fish</u>

The majority of whitebait were measured after freezing, but a small proportion of fish were measured twice: first when fresh and then after being frozen and defrosted to calculate a conversion factor (see Appendix 3).

3.2.2 Statistical Analyses

3.2.2.1 Composition

3.2.2.1.1 Species composition across regions

Regions with two or more rivers sampled within each month (with at least 100 fish per sample) were used for statistical analyses of species composition. These included the months of September, October and November (Table 3.1). Where multiple samples were collected on the same river within a calendar month the average composition across the samples was used for the analyses.

Table 3.1. Regions and number of rivers used in the analyses of species composition across regions.

Regions	**September (number of rivers)**	**October (number of rivers)**	**November (number of rivers)**
Waikato	4*	6*	5*
Bay of Plenty	5*	6	NA
Taranaki	3*	NA	NA
Manawatu – Wanganui	3*	2*	3*
Hawkes Bay	2	5*	2*
Wellington	NA	4*	NA
Tasman – Nelson	NA	3*	NA
Marlborough	NA	3*	NA
Canterbury	4*	6*	10*
Otago	NA	5	3*
Southland	5*	4*	4*
Buller	7*	6*	5*
Westland	7*	6*	6*

* = multiple samples were averaged in this region during a calendar month.

A Permutational Multivariate Analysis of Variance (PERMANOVA) (Anderson, 2001) was used to compare whitebait assemblages between regions in September, October and November. The PERMANOVA was run on PRIMER V6 using a Bray-Curtis dissimilarity matrix on untransformed data with 9999 permutations. Each PERMANOVA had one fixed factor (region). The data were displayed using principle coordinate analysis (PCO) plots.

PRIMER only provides t-tests as post hoc comparisons, which in this case resulted in a large number of pairwise comparisons (21 to 66 depending on the month) because of the nature of the experimental design. Such a large number of non-independent comparisons inflates the probability of Type I error and poses serious interpretation difficulties. To avoid these problems, post-hoc comparisons among regions were based on their relative position in Euclidean space. To do this, the observations were placed into Euclidean space by calculating principal coordinates (Gower, 1966) from a Bray-Curtis dissimilarity matrix including the full set of data, separately for each month. I then calculated the overall centroid of all observations (analogous to the grand mean in univariate analyses) and measured the Euclidean distance between each sample and the overall centroid. Regions with similar species composition would also have similar Euclidean distances from the overall centroid, while large Euclidean distances would indicate differences in species composition. Distance measures were analysed with a one-way ANOVA with the fixed factor "Region" and by Newman-Keuls (SNK) post-hoc tests.

One way ANOVA analyses were used to compare the proportional abundance of each whitebait species across regions. This was only possible for inanga in September, and inanga, koaro and banded kokopu in October and November as the other species were scarce in samples. Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. Where Cochran's test for homogeneity of variances remained significant following data transformation the results were interpreted with caution by lowering the significance level to 0.01 (Underwood, 1997).

3.2.2.1.2 Species composition within regions

Spatial graphs with species composition in rivers within regions only used samples with 10+ fish. During each month (July to December) data were used from multiple sites on rivers if they existed, but when two samples existed from the same site on the same river the sample sizes closest to 200 fish was selected (the exception was on the Waimea Creek during November when shortjaw kokopu were found in a small sample and both samples were included).

For statistical analysis, rivers within regions with at least 100 fish were used as above for the months of September, October and November. To quantify variability in species composition across rivers within each region, a Permutational Multivariate Analysis of Dispersions (PERMDISP) (Anderson, 2006) was used to test for differences in patterns of multivariate dispersions across regions (differences between rivers) separately for each month. PERMDISP analyses included one fixed factor (region) and were run on PRIMER V6 using a Bray-Curtis dissimilarity matrix.

For each month, a one-way ANOVA with fixed factor 'Region" and SNK post-hoc tests were used for the analysis of PERMDISP values (expressing the distance of each river from the centroid of its region). Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. Where Cochran's test for homogeneity of variances remained significant following data transformation the significance level was lowered to 0.01 (Underwood, 1997).

3.2.2.2 Morphology

3.2.2.2.1 Morphology across and within regions

The total length, body depth, and wet weight were collected for whitebait from July to December during the 2015 study. Inanga were caught throughout the 6 months in multiple regions from July to December (Fig. 3.25. to 3.27). Koaro and banded kokopu were mainly caught from September to November (Fig. 3.28 to 3.33). Giant kokopu were caught from September to December, but due to the low numbers, monthly data have been combined to compare regions and rivers (Fig. 3.34).

Condition indices (relative weight) were calculated for each species to determine the plumpness of fish using methods by Murphy et al. (1990).

The standard weight (W_s) for each species were:

Inanga	$W_s = 0.00000197179\text{length}^{3.093109}$
Koaro	$W_s = 0.00000053319\text{length}^{3.494605}$
Banded kokopu	$W_s = 0.00000890648\text{length}^{2.749087}$
Giant kokopu	$W_s = 0.00000188601\text{length}^{3.279272}$

Relative weight (W_r) for each fish was calculated using the equation: 100 x W/W_s where W is the wet weight.

Subsamples of fish for morphology measurements contained 36 randomly selected individuals as well as the two largest (total length) and smallest fish. The largest and smallest fish were used to calculate standard weights (see above), but were not included in further statistical analyses.

Regions with two or more rivers sampled within each month with at least 10 fish (inanga) and at least 5 fish for the other species were used for statistical analyses. These included the months of September, October and November for inanga, koaro, and banded kokopu. For giant kokopu, data from the months of October, November and December were combined due to the low numbers of fish caught. Shortjaw kokopu was excluded from the analyses due to the very low number of fish caught. Where multiple samples from the same river were available, the average total length, body depth and relative weight was calculated.

One-way ANOVA and SNK post-hoc tests were used to compare the length, relative weight and body depth of inanga, koaro, banded kokopu and giant kokopu across regions, separately for each month. Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. Where Cochran's test for homogeneity of variances remained significant following data transformation the significance level was lowered to 0.01 (Underwood, 1997).

3.2.2.2.2 Influence of latitude on length

Analysis of Covariance (ANCOVA) was used to test for variations in inanga, koaro and banded kokopu length between coasts and across a latitudinal gradient encompassing the entire country. The ANCOVA included the fixed factor 'Coast' (West Coast vs. East Coast of New Zealand) with river mouth latitude (decimal degrees) as a covariate. Data from all samples from September to November were included in this analysis, but fish from Southland, Tasman-Nelson, Marlborough and some rivers in Wellington were excluded as they could not be allocated to the East or West Coast.

An ANCOVA could not be used to test variations in giant kokopu length between coasts and latitude as too few giant kokopu were recorded on the East Coast of New Zealand. Therefore, a simple regression was used to test for variations in giant kokopu length across New Zealand's latitudinal gradient.

3.2.2.3 Environmental variables

Environmental variables were obtained using the Freshwater Ecosystems of New Zealand (FENZ) and the River Environment Classification 2.0 version 3 (REC) databases (Leathwick et al., 2005; Leathwick et al., 2008; Crow et al., 2014). The environmental variables included in the analyses were: 1) catchment area, 2) indigenous forest cover, and 3) pasture cover.

Data used in statistical analysis in 3.2.2.2.1 were used again to assess the relationship between whitebait species composition and the three environmental variables. These variables were used because non-inanga species as adults prefer forest-covered streams as opposed to pasture covered streams (McDowall, 2000; Baker & Smith, 2007). Catchment size is a measure of the size of the river and may also have an effect on species composition.

Rivers for which measurements of environmental variables were not available were removed from the dataset.

Distance based linear models (DISTLM) (Anderson et al., 2008) were used to test the influence of forest cover, pasture cover and catchment size on species composition of whitebait. September, October and November data were analysed separately. I initially built a model including the three variables, and subsequently removed the variables with little predictive power to obtain the most parsimonious model. Adjusted R^2 values were used to judge model predictive power. The variables retained in the model were also included as co-variables in the PERMANOVA analyses including the fixed factor “Region”. For each month, PERMANOVA was run with and without the environmental predictors to re-assess variability in species composition among regions net of the effect of the selected co-variables.

Univariate analyses were used to further analyse these data. The Pearson correlation coefficient was used to assess the relationship between the abundance of each species and forest /pasture cover or catchment area, separately for each month. The strength of the relationship between the abundance of each species and the three environmental variables was further tested with multiple regression models. For each species in each month, I built a model including the three variables, and subsequently removed the variables with little predictive power to obtain the most parsimonious model. Adjusted R^2 values were used to judge model predictive power.

3.3 RESULTS

3.3.1 Composition

3.3.1.1 Whitebait species in samples and overall composition

All five whitebait species were found in samples collected throughout New Zealand during the 6-month 2015 field study.

Inanga were the most widespread fish, being found in every region and all rivers sampled apart from the Hapuku River (Canterbury) in November. Banded kokopu were present in each region, but were absent from some rivers.

Samples in all regions included koaro except Auckland and Coromandel. Giant kokopu were present in Waikato, Manawatu-Wanganui, Wellington, Tasman-Nelson, Buller and Westland. Shortjaw kokopu were found rarely, but were recorded in Bay of Plenty, Manawatu-Wanganui, Buller and Westland (Fig. 3.6, Table 3.2).

Species composition over the entire study varied from region to region. For example, Bay of Plenty samples were comprised of 94.7% inanga, 1.2% koaro, 4.1% banded kokopu and 0.02% shortjaw kokopu, while Tasman-Nelson samples comprised of 74.8% inanga, 12.0% koaro, 13.0% banded kokopu and 0.11% giant kokopu. The species composition over the whole of New Zealand was 88.2% inanga, 5.0% koaro, 6.6% banded kokopu, 0.3% giant kokopu and 0.01% shortjaw kokopu (Fig. 3.6, Table 3.2).

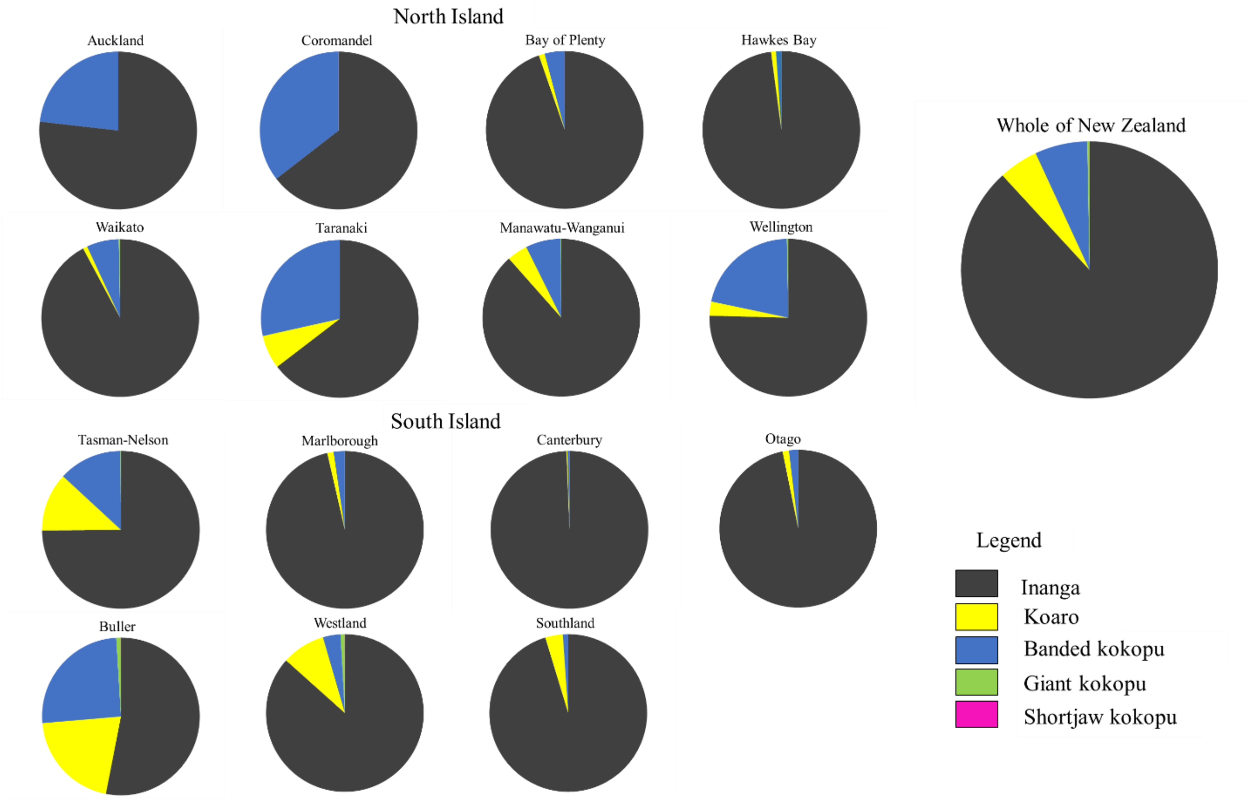


Figure 3.6. Summary of overall species composition from all samples (see Table 3.2 for summary data). Note: Auckland and Coromandel included only a single river and were not used when calculating species composition for the whole of New Zealand.

Table 3.2. Summary of overall species presence/absence and mean species composition (+SE) from all whitebait samples.

		Proportion of Whitebait Catch (%)							
		Inanga (*G. maculatus*)	**Koaro (*G. brevipinnis*)**	**Banded kokopu (*G. fasciatus*)**	**Giant kokopu (*G. argenteus*)**	**Shortjaw kokopu (*G. postvectis*)**	**Number of Samples**	**Number of Rivers**	**Months Whitebait Caught**
North Island	**Auckland**	76.8 (20.1)		23.2 (20.1)			3	1	Oct/Nov
North Island	**Coromandel**	64.5 (9.3)		35.5 (9.26)			4	1	Oct/Nov
North Island	**Waikato**	92.2 (1.7)	0.9 (0.2)	6.6 (1.6)	0.30 (0.10)		55	7	Jul/Aug/Sep/Oct/Nov/Dec
North Island	**Bay of Plenty**	94.7 (2.4)	1.2 (0.6)	4.1 (2.4)		0.02 (0.02)	25	9	Jul/Aug/Sep/Oct/Nov
North Island	**Taranaki**	64.6 (8.3)	6.9 (4.3)	28.5 (10.1)			5	3	Sep
North Island	**Manawatu/ Wanganui**	88.5 (3.9)	4.2 (1.6)	7.2 (3.2)	0.14 (0.11)	0.003 (0.003)	14	5	Sep/Oct/Nov
North Island	**Hawkes Bay**	97.9 (0.5)	1.0 (0.3)	1.1 (0.3)			18	6	Jul/Aug/Sep/Oct/Nov
North Island	**Wellington**	75.5 (8.6)	2.9 (1.6)	21.4 (8.4)	0.32 (0.21)		9	6	Sep/Oct/Nov
South Island	**Tasman/ Nelson**	74.8 (5.4)	12.0 (3.4)	13.0 (4.3)	0.11 (0.06)		18	4	Jul/Aug/Sep/Oct/Nov/Dec
South Island	**Marlborough**	96.5 (0.9)	1.3 (0.5)	2.3 (0.7)			10	4	Sep/Oct/Nov
South Island	**Canterbury**	99.4 (0.2)	0.2 (0.1)	0.4 (0.1)			38	14	Aug/Sep/Oct/Nov/Dec
South Island	**Otago**	96.8 (1.2)	1.3 (0.4)	1.9 (1.0)			11	5	Oct/Nov
South Island	**Buller**	53.1 (6.9)	20.6 (4.8)	25.4 (6.3)	0.92 (0.60)	0.05 (0.03)	27	8	Aug/Sep/Oct/Nov/Dec
South Island	**Westland**	86.6 (2.8)	8.9 (2.5)	3.6 (1.1)	0.85 (0.6)	0.04 (0.04)	45	8	Jul/Aug/Sep/Oct/Nov/Dec
South Island	**Southland**	95.3 (1.4)	3.6 (1.2)	1.1 (0.4)			44	6	Aug/Sep/Oct/Nov
Whole of New Zealand		88.2 (1.2)	5.0 (0.7)	6.6 (0.9)	0.3 (0.1)	0.01 (0.006)	319	85	Jul/Aug/Sep/Oct/Nov/Dec

Note: The table includes regions with two or more rivers with sample sizes of at least 50 fish apart from Auckland and Coromandel which included samples from a single river (SE in brackets).

3.3.1.2 Species composition among regions

Inanga comprised the majority of whitebait samples in all regions in New Zealand throughout September, October and November (proportional abundance >55% in all regions). The exception was Buller in October where banded kokopu dominated samples (63%) (Fig. 3.7, 3.8 & 3.9).

There were obvious differences in species composition between the West and East Coasts of the North and South Islands. There were very high proportions of koaro and banded kokopu in West Coast regions, but low proportions in East Coast regions (Fig. 3.8). For example, samples from Hawkes Bay, Otago and Canterbury (East Coast) consisted of approximately 95% inanga in all three months, but Waikato, Taranaki, Buller and Westland (West Coast) had high proportions of non-inanga species at some stage during September, October and November (Waikato = 16%, October; Taranaki = 35%, September; Buller = 77%, October; Westland = 23%, October) (Fig. 3.7, 3.8 & 3.9).

Giant kokopu and shortjaw kokopu were very rare in samples from throughout New Zealand with proportions of giant kokopu less than 2.1%, and shortjaw kokopu less than 0.2% across all regions.

September

In September, PERMANOVA results showed significant differences in whitebait species composition among regions (Pseudo-$F_{8,31}$=3.32, P<0.01; Table 3.3; Fig. 3.10). In contrast, ANOVA on Euclidean distances showed that there were no significant differences in the positioning of the regions relative to the overall centroid in Euclidean space ($F_{8,31}$=1.59, P 0.168; Table 3.3; Fig. 3.11). A visual inspection of the data (Fig. 3.19) showed that most samples from rivers were clustered together, but with several outliers. The discrepancy between the two analyses may have been caused by the higher sensitivity of PERMANOVA to the presence of such outliers.

Species composition of inanga differed significantly among regions in September ($F_{8,31}$=3.47, P <0.01). SNK tests showed that Canterbury, Southland, Hawkes Bay and the Bay of Plenty had higher proportions of inanga than Buller, Waikato and Westland. In September, Taranaki had the lowest proportion of inanga (around 65%; Fig. 3.7).

October

In October, whitebait assemblage composition differed among regions (Pseudo-$F_{11,44}$=8.18, P <0.001; Table 3.3; Fig. 3.10). The analysis of Euclidean distances showed that the Buller region was significantly more distant from the overall centroid compared to all other regions ($F_{11,44}$=9.05, P <0.001; Table 3.3; Fig. 3.11). Buller samples consisted of 23% inanga, 15% koaro and 63% banded kokopu (Fig. 3.8).

Univariate analyses found significant differences among regions in October for inanga ($F_{11,44}$=10.433, P <0.001), koaro ($F_{11,44}$=2.788, P <0.01) and banded kokopu ($F_{11,44}$=7.508, P <0.001) (Table 3.3). SNK post hoc tests showed that Buller was always significantly different to the other regions as samples consisted of lower proportions of inanga and higher proportions of koaro and banded kokopu.

November

In November, species composition differed among regions (Psuedo-$F_{7,30}$=2.538, P <0.05; Table 3.3; Fig. 3.10). The analysis of Euclidean distances showed that the Buller region was significantly more distant from the overall centroid compared to all other regions ($F_{7,30}$=3.008, P=<0.05; Table 3.3; Fig. 3.11).

Univariate analyses found significant differences among regions in November for inanga ($F_{7,30}$=3.843, P <0.001), but not for koaro ($F_{7,30}$=2.129, P =0.07), and banded kokopu ($F_{7,30}$=1.477, P =0.21) (Table 3.3). SNK post hoc tests showed that Buller was different to the other regions as it had lower proportions of inanga in samples.

Table 3.3. Results of PERMANOVA, and ANOVA of Euclidean distances and species analyses testing variations in species composition across regions for each month.

Month	**Analysis**	**Source of variation**	**SS**	**df**	**F or Pseudo-F**	**P**
September	PERMANOVA	Region	4802.2	8	3.32	<0.01
		Residual	5597.7	31		
		Total	10400	39		
	Euclidean distance ANOVA	Region	1551.29	8	1.59	0.17
		Residual	3780.01	31		
	Inanga ANOVA	Region	4567.4	8	3.47	<0.001
		Residual	5100.1	31		
October	PERMANOVA	Region	30104	11	8.18	<0.001
		Residual	14726	44		
		Total	44829	55		
	Euclidean distance ANOVA	Region	10823.11	11	9.05	<0.001
		Residual	4782.49	44		
	Inanga ANOVA	Region	30258.7	11	10.4	<0.001
		Residual	11601.3	44		
	Koaro ANOVA	Region	1962.79	11	2.79	<0.01
		Residual	2817.24	44		
	Banded kokopu ANOVA	Region	22356.46	11	7.51	<0.001
		Residual	11910.16	44		
November	PERMANOVA	Region	4513.6	7	2.54	<0.05
		Residual	7622.8	30		
		Total	12136	37		
	Euclidean distance ANOVA	Region	3167.927	7	3.01	<0.05
		Residual	4512.83	30		
	Inanga ANOVA	Region	5453.5	7	3.84	<0.01
		Residual	6082.6	30		
	Koaro ANOVA	Region	2445.19	7	2.13	0.07
		Residual	4922.35	30		

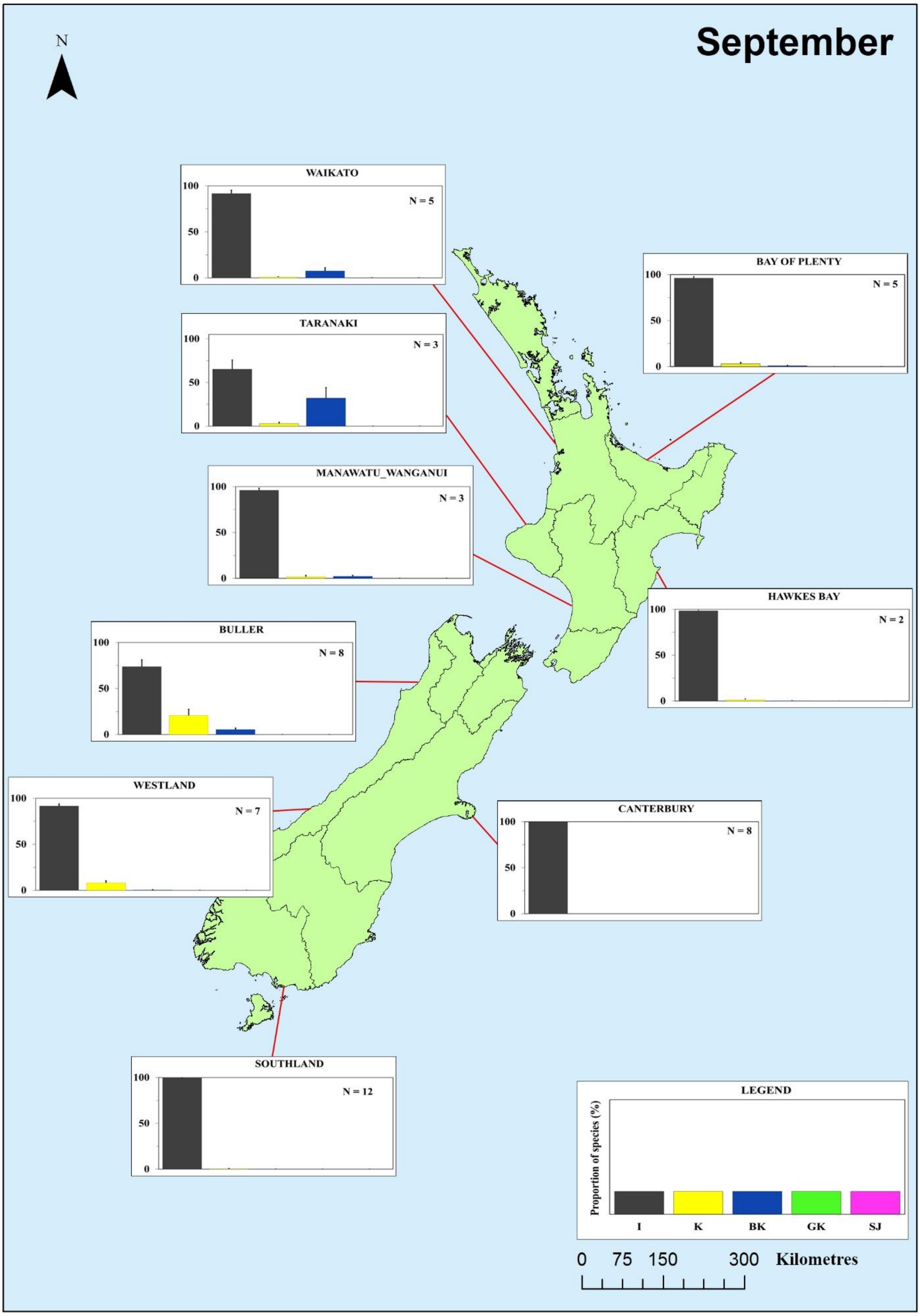


Figure 3.7. Mean (+SE) species composition from 9 regions during September 2015, N = number of rivers. Species codes: I=inanga, K=koaro, BK=banded kokopu, GK=giant kokopu, SJ=shortjaw kokopu.

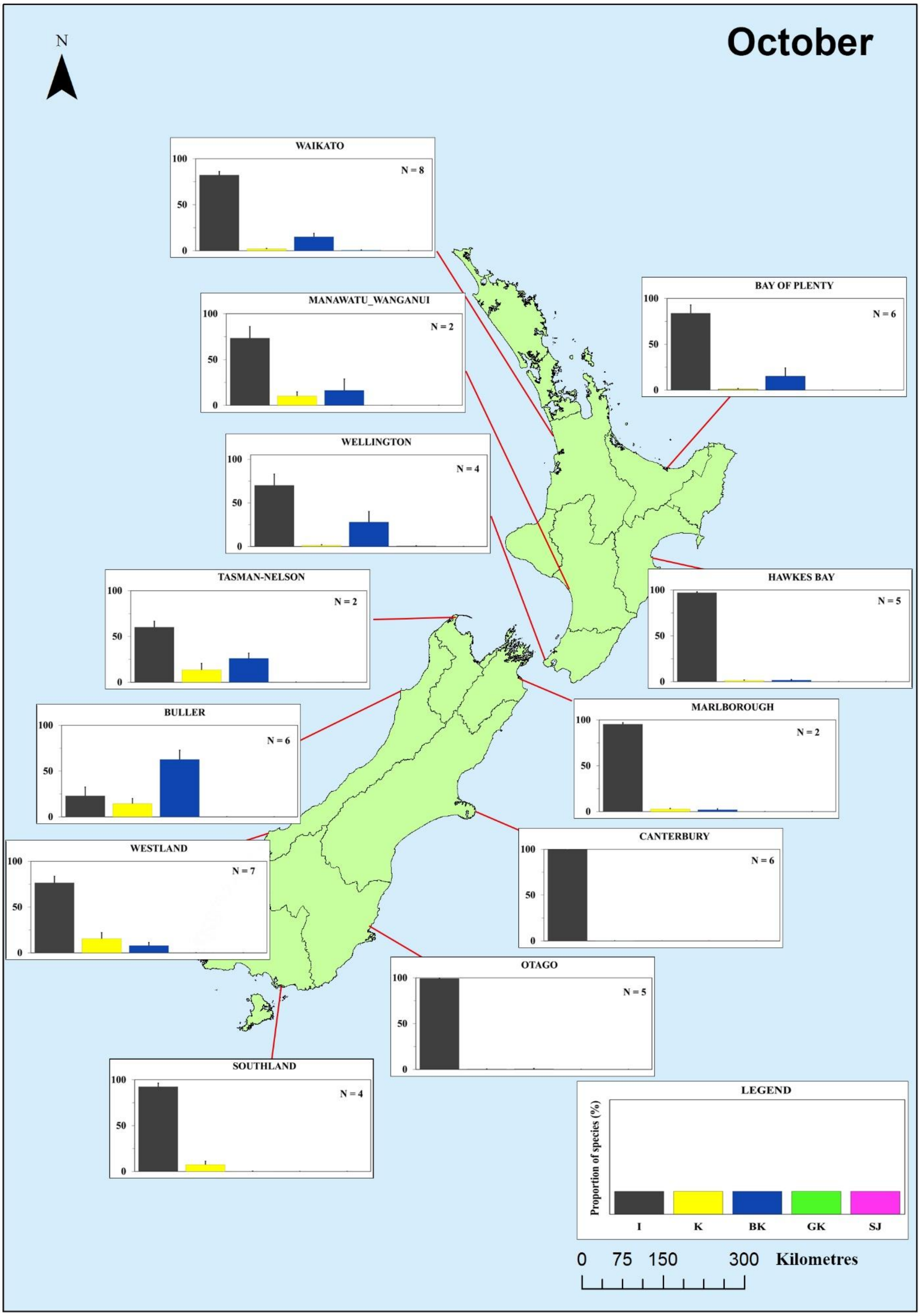


Figure 3.8. Mean (+SE) species composition from 12 regions during October 2015, N = number of rivers. Species codes: I=inanga, K=koaro, BK=banded kokopu, GK=giant kokopu, SJ=shortjaw kokopu.

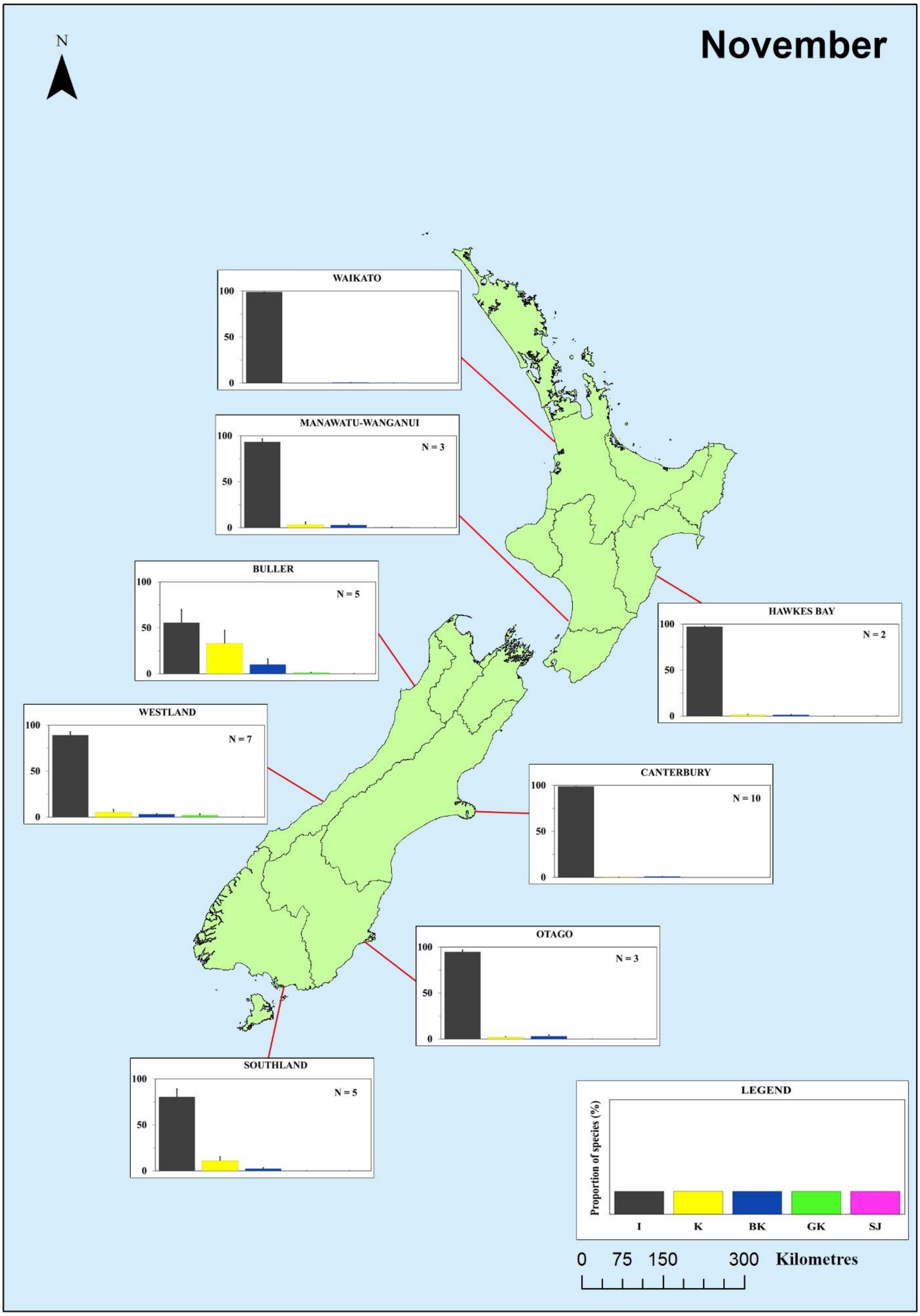


Figure 3.9. Mean (+SE) abundance of whitebait species composition from 8 regions during October 2015, N = number of rivers. Species codes: I=inanga, K=koaro, BK=banded kokopu, GK=giant kokopu, SJ=shortjaw kokopu.

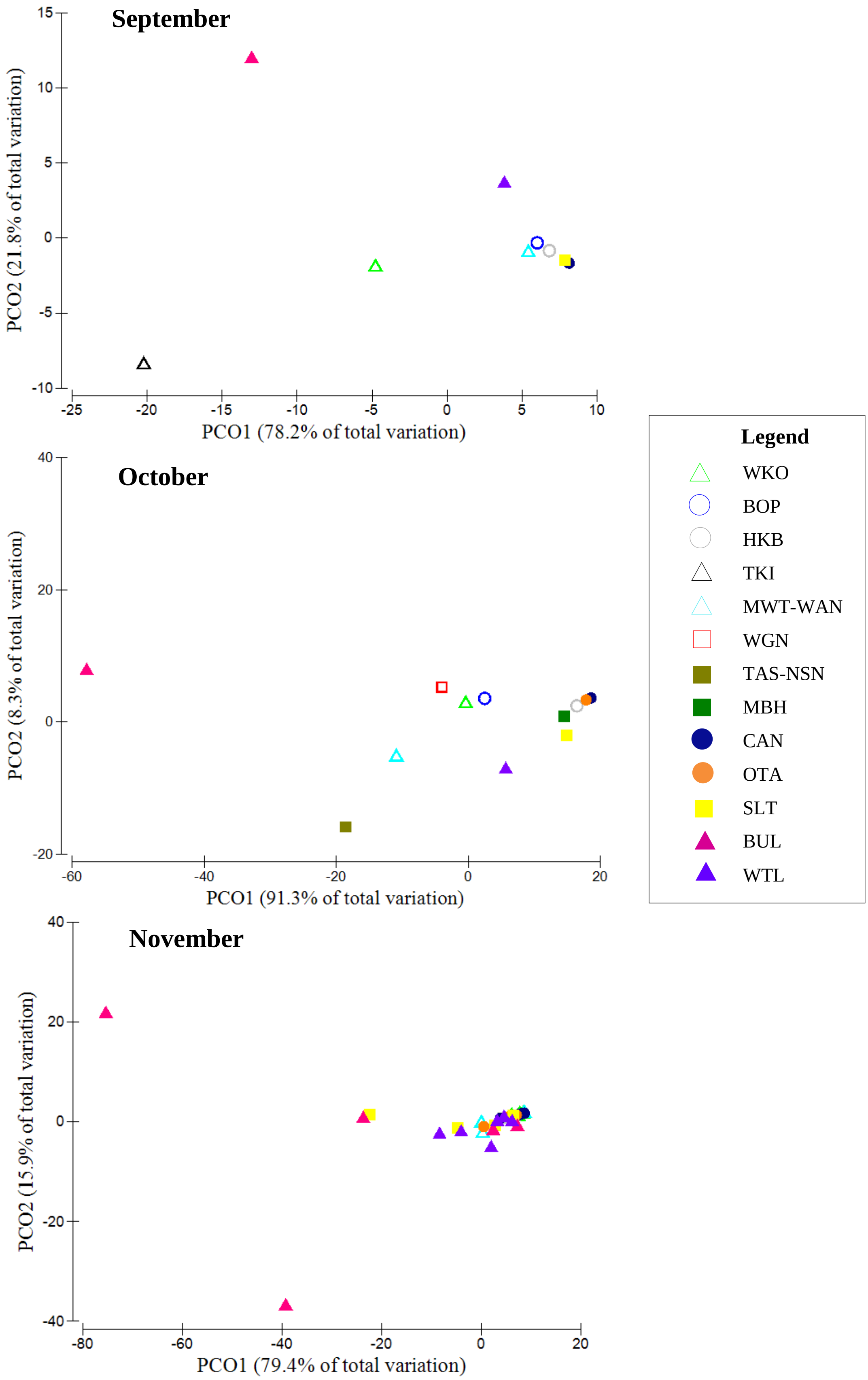


Figure 3.10. PCO plots showing variations in species composition among regions in September, October and November. Symbols represent species composition centroids for each region. Abbreviations for regions were: Waikato (WKO), Bay of Plenty (BOP), Hawkes Bay (HKB), Taranaki (TKI), Manawatu-Wanganui (MWT-WAN), Wellington (WGN), Tasman-Nelson (TAS-NSN), (Marlborough (MBH), Canterbury (CAN), Otago (OTA), Southland (SLT), Buller (BUL), and Westland (WTL).

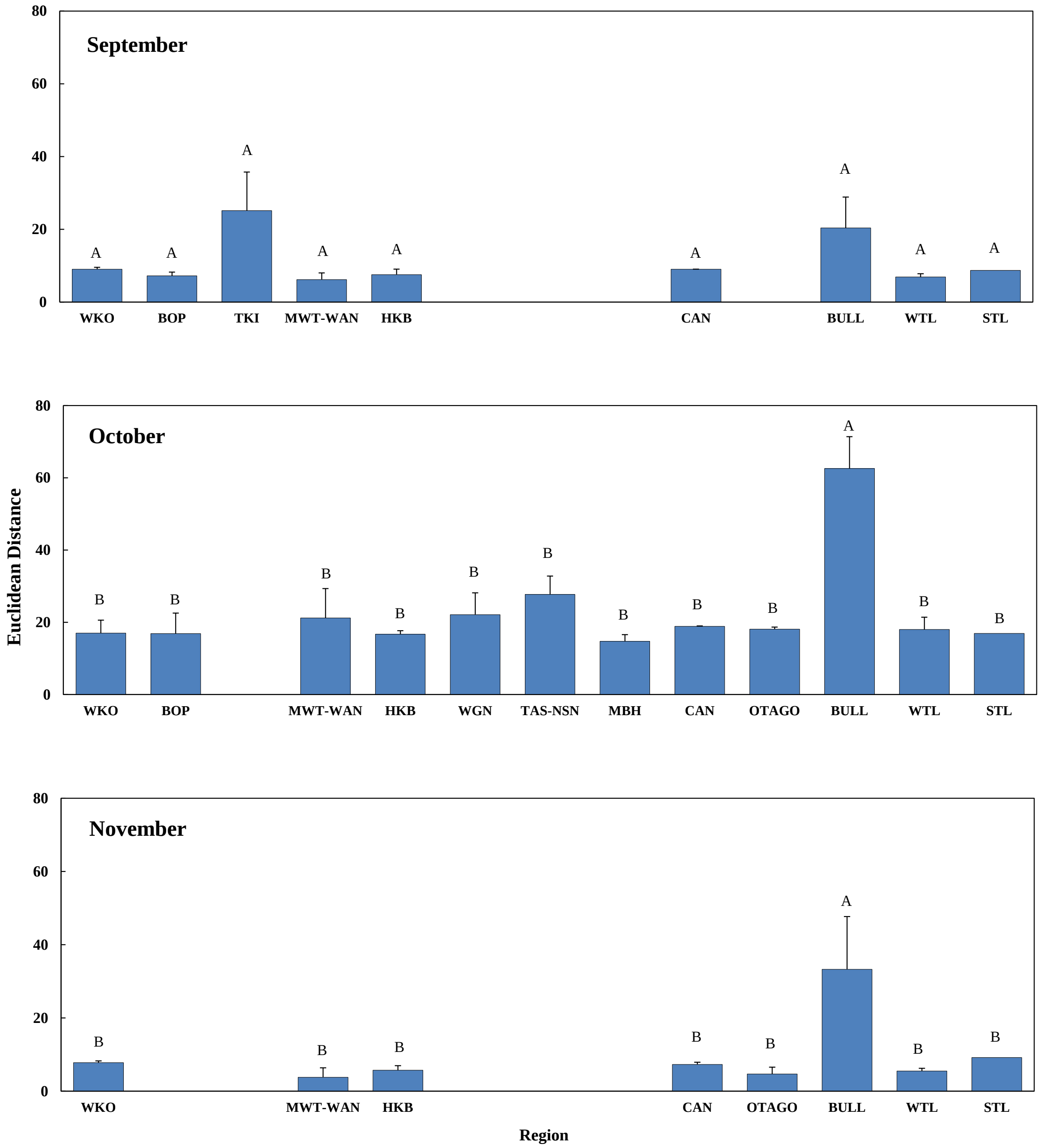


Figure 3.11. Mean (+SE) Euclidean distances showing the separation of each region from the overall observation centroid in September, October and November. Regions with similar species composition also share similar Euclidean distances (letters A-B show results of Newman-Keuls post hoc test). See Fig. 3.10 for region abbreviations.

3.3.1.3 Species composition within regions

Inanga were found to make up the majority of whitebait samples in rivers throughout New Zealand (Fig. 3.12 to 3.17), but on some rivers, and at certain times of the year, non-inanga species made substantial contributions. For example, on the Hapuku River (Canterbury) a sample taken in November was comprised of 92% Koaro and 8% banded kokopu (Fig. 3.16). Similarly, on the Oparara and Little Wanganui Rivers (Buller) samples during October were comprised of over 90% banded kokopu, and the Waiatoto River (Westland) 94% koaro (Fig. 3.15).

While species composition during a month was consistent in samples from Buller Rivers, there was variation within the Waiatoto River (Westland). For example, in October one sample from the Waiatoto River consisted of 94% koaro and another consisted of only 30% koaro (Fig. 3.15).

During the months of July, and August inanga dominated whitebait samples from rivers across New Zealand. For example, during August all samples from rivers in Bay of Plenty, Waikato, Canterbury and Southland consisted of 99% inanga (Fig. 3.13).

During September and October greater proportions of non-inanga species were observed in whitebait samples. Koaro were found in most rivers in Westland and Buller during September, and banded kokopu were present mainly in Waikato rivers (Fig. 3.14). During October, higher proportions of banded kokopu were found in Buller, Tasman-Nelson, Waikato and Bay of Plenty rivers (Fig. 3.15). In contrast, during November the proportion of banded kokopu dropped in samples from these regions and was replaced with higher proportions of inanga (Fig. 3.16).

On the East Coast of the North and South Island (Bay of Plenty, Hawkes Bay, Canterbury, Otago) in all months inanga made up the highest proportion of samples in rivers.

Giant kokopu and shortjaw kokopu were observed in low proportions in samples throughout the 6 months study. They were observed on mainly the West Coasts of the North and South Islands (Fig. 3.18). Larger proportions of giant kokopu and shortjaw kokopu were observed in November. On the Waimea Creek one sample in November consisted of 25% giant kokopu, whereas most other samples were >2%. Shortjaw kokopu were recorded from Whakatane

River (Bay of Plenty), Rangitikei River (Manawatu-Wanganui), Orowaiti & Buller Rivers (Buller) and Waimea Creek (Westland).

3.3.1.3.1 Statistical Analyses

PERMDISP tests showed that multivariate dispersion (due to composition differences among rivers and within regions) was unequal across regions in October ($F_{11,44}$=4.58, P <0.05) and November ($F_{7,30}$=10.67, P <0.05) but not in September ($F_{8,31}$=4.00, P =0.294) (Table 3.4; Fig. 3.20). This indicates that the species composition of whitebait samples across rivers is more heterogeneous in certain regions than others.

ANOVA and Newman-Keuls (SNK) post hoc tests showed that in September ($F_{8,31}$=12.75, P <0.001; Table 3.4), Taranaki and Buller had significantly higher multivariate dispersion (i.e, greater variation among rivers) than all other regions. For example, samples on the Waitara and Onaero Rivers in Taranaki had roughly 60-70% inanga and 30-35% banded kokopu, whereas the Waingongoro River had 92% inanga and 8% koaro (Fig. 3.14).

In October ($F_{11,44}$=4.58, P <0.001; Table 3.4), Buller and Wellington had the highest multivariate dispersion, while Canterbury, Otago and Hawkes Bay had the lowest (details of ANOVA results missing). In Buller, the Karamea and Mokihinui Rivers had samples with high proportions of non inanga species (68% Koaro in the Karamea River; 47% banded kokopu in the Mokihinui River), whereas the Orowaiti, Buller and Punakaiki Rivers had samples with high proportions of inanga (around 92%). Similarly, on all 7 rivers sampled in October in Canterbury inanga made up 100% of all samples (Fig. 3.15).

In November ($F_{7,30}$=21.04, P <0.001; Table 3.4), Buller had significantly higher multivariate dispersion than all other regions but Southland and Westland also grouped together (Fig. 3.16).

Table 3.4. Results of PERMDISP, ANOVA analyses testing variations in species composition across rivers in regions for each month.

Month	**Analysis**	**Source of variation**	**SS**	**df**	**F**	**P**
September	PERMDISP	Region	NA	8,31	4.00	0.29
	PERMDISP ANOVA	Region	6.01	8	12.75	<0.001
		Residual	1.83	31		
October	PERMDISP	Region	NA		4.58	<0.05
	PERMDISP ANOVA	Region	4014.90	11	4.58	<0.001
		Residual	3503.90	44		
November	PERMDISP	Region	NA	7,30	10.67	<0.05
	PERMDISP ANOVA	Region	6.20	7	21.04	<0.001
		Residual	1.26	30		

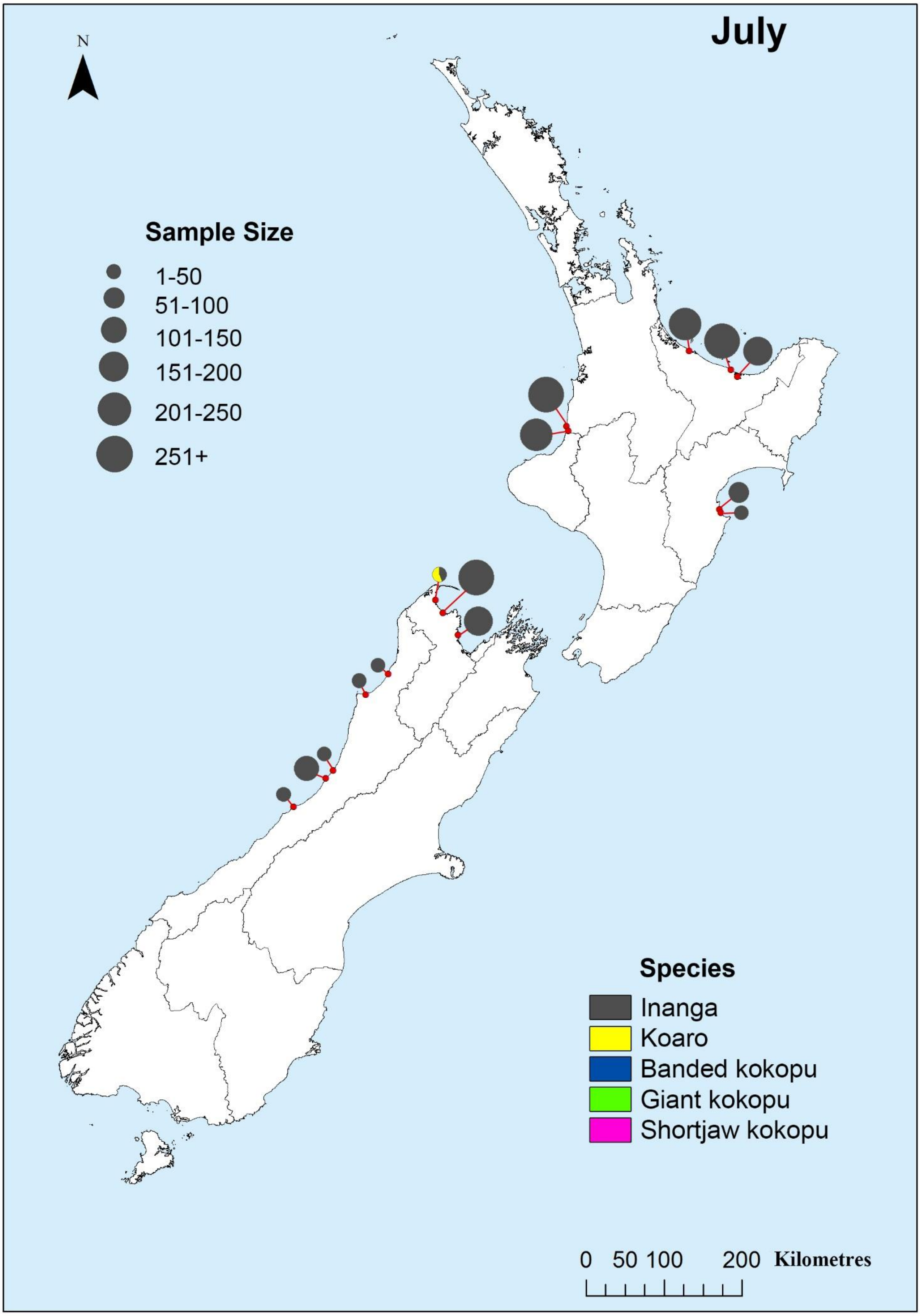


Figure 3.12. Species composition of samples from 15 rivers during July 2015.

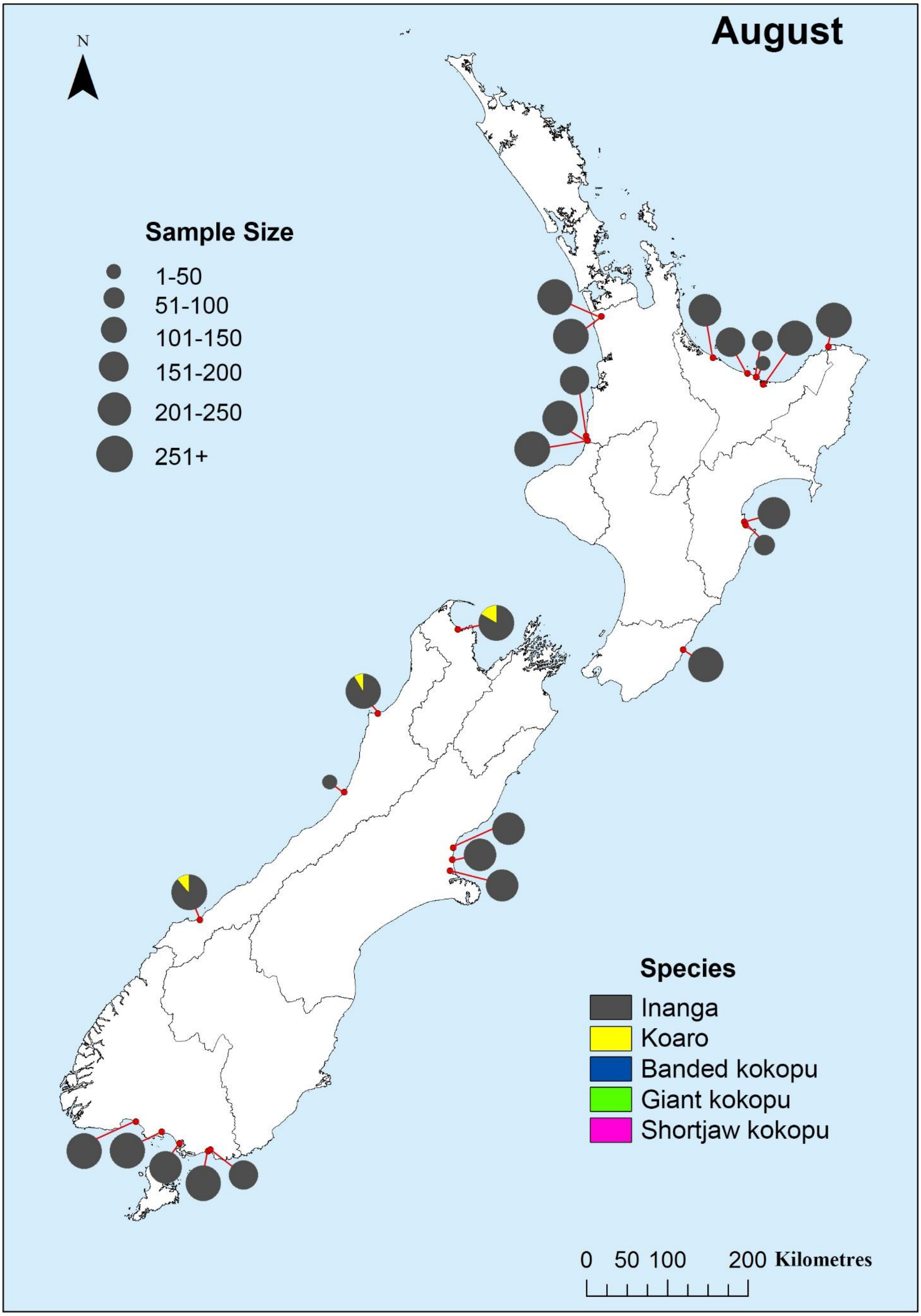


Figure 3.13. Species composition of whitebait samples from 23 rivers during August 2015 (3 rivers had multiple samples at different sites).

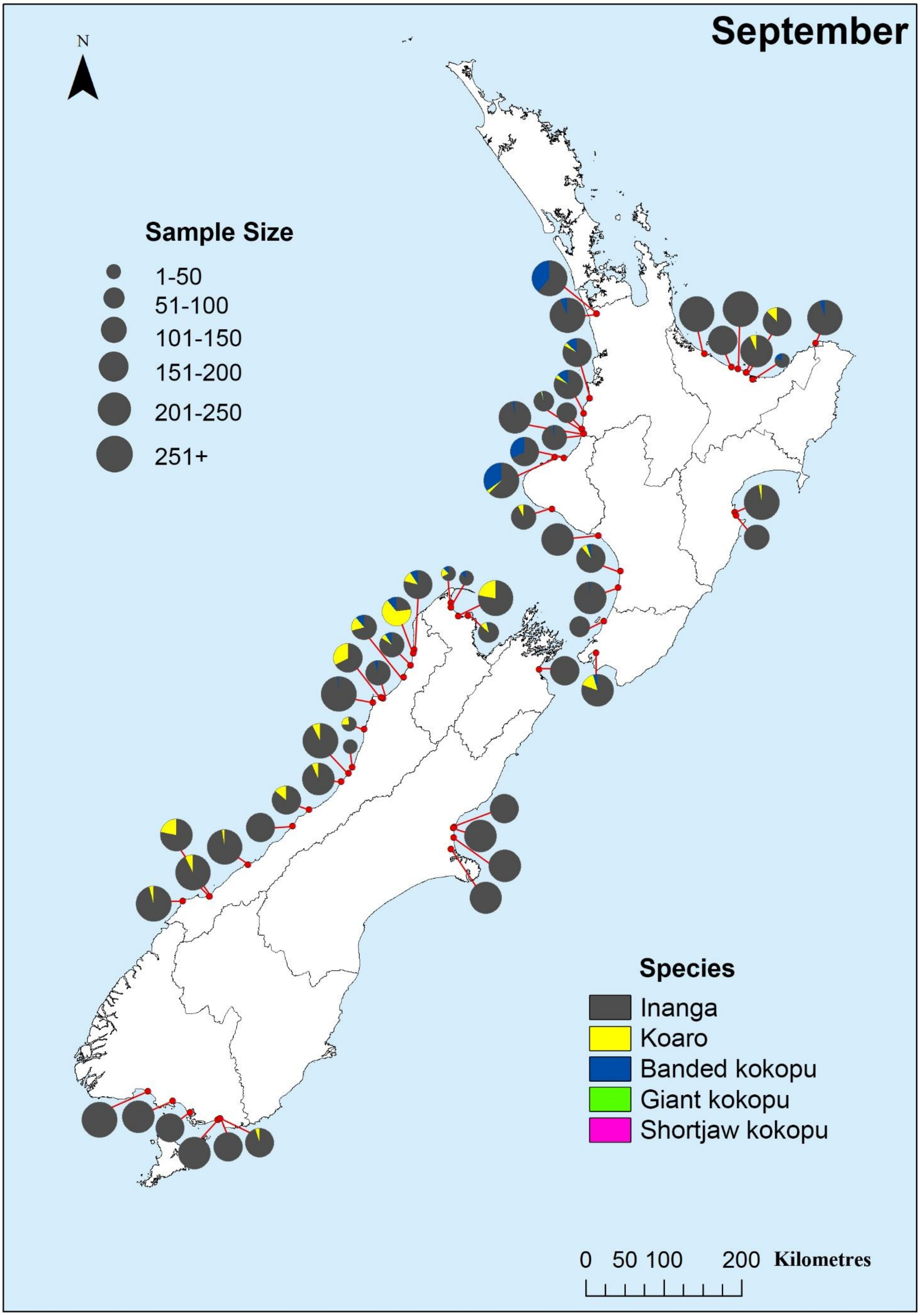


Figure 3.14. Species composition of whitebait samples from 51 rivers during September 2015 (7 rivers had multiple samples at different sites).

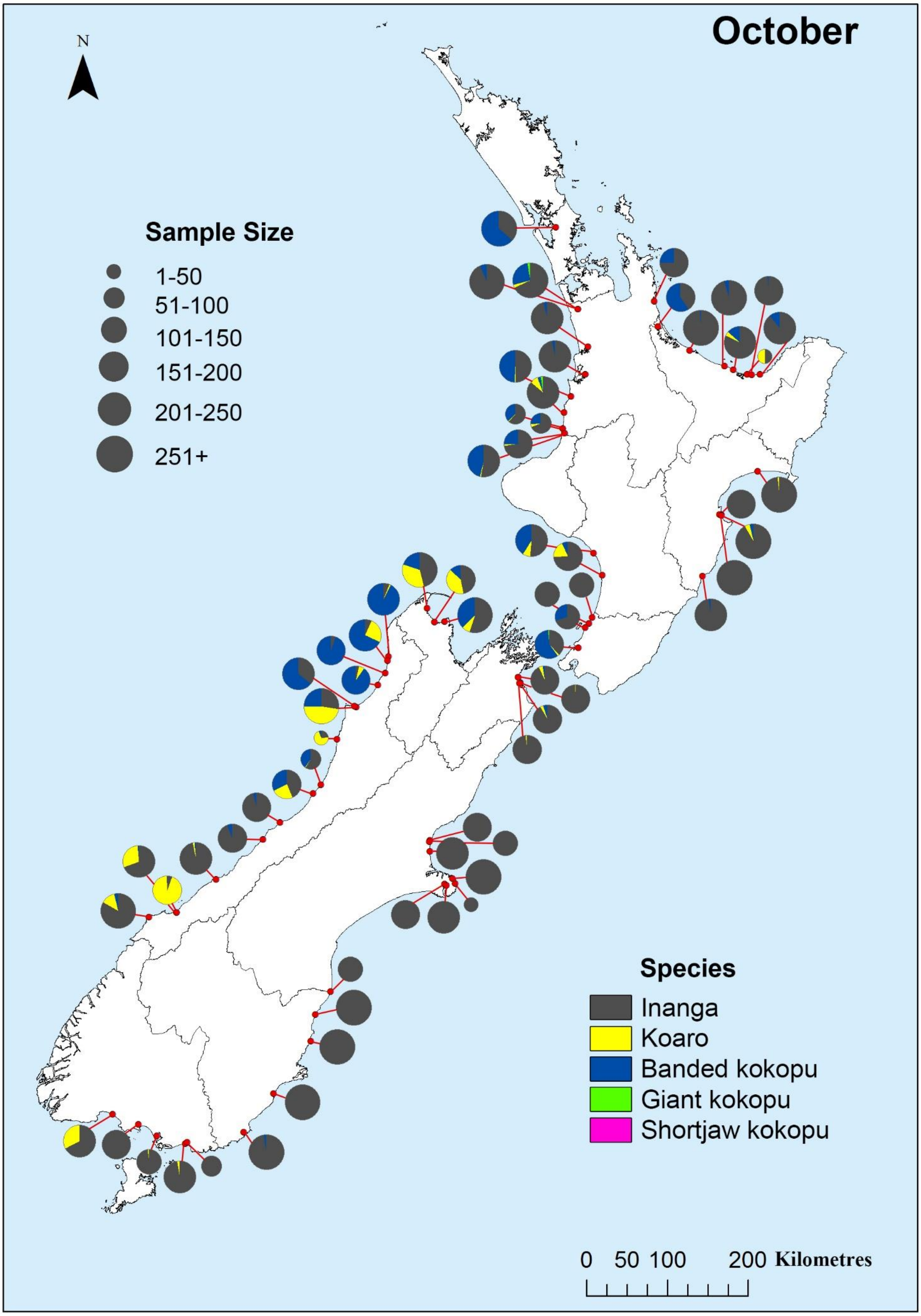


Figure 3.15. Species composition of whitebait samples from 64 rivers during October 2015 (6 rivers had multiple samples at different sites).

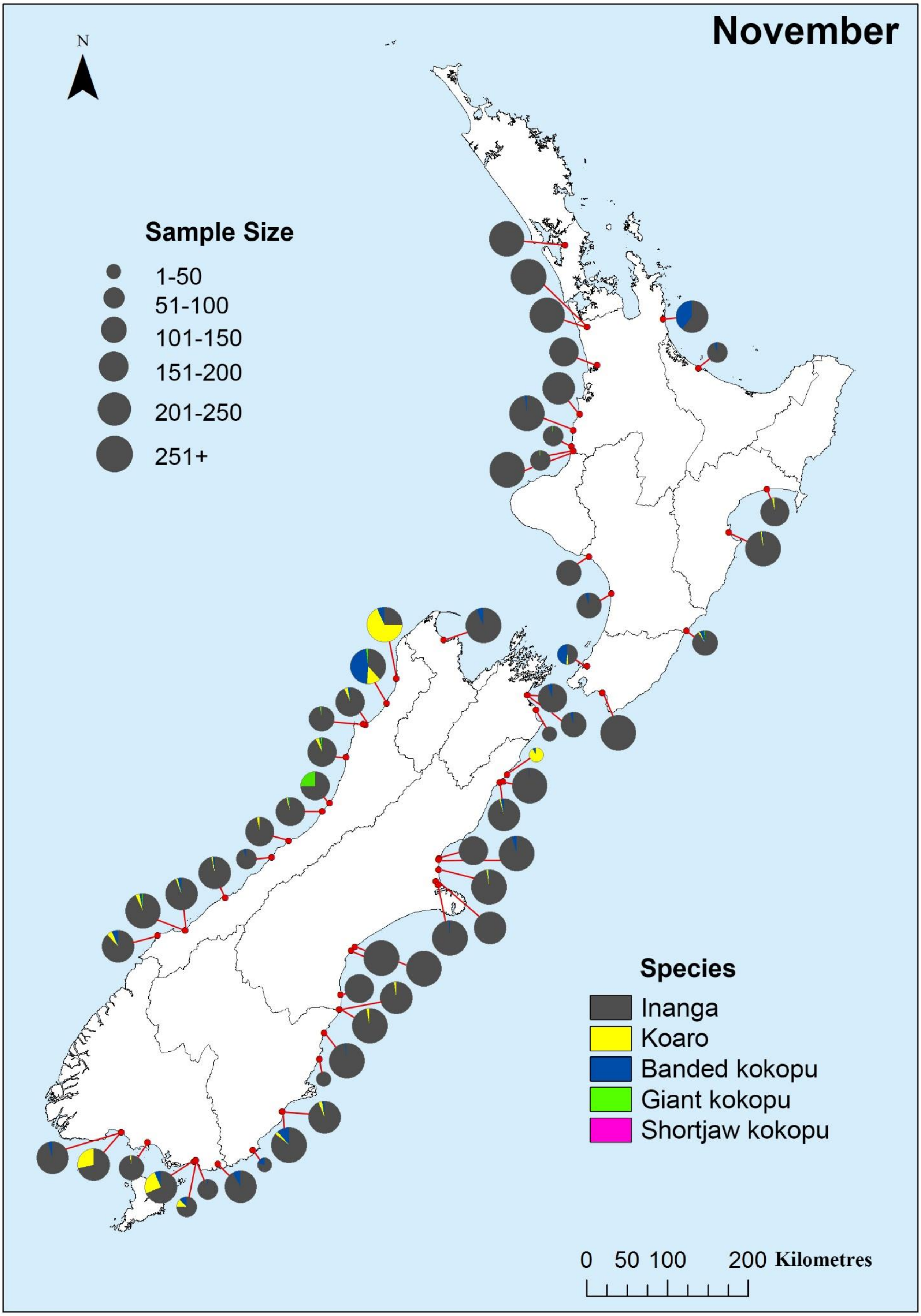


Figure 3.16. Species composition of whitebait samples from 52 rivers during November 2015 (11 rivers had multiple samples at different sites).

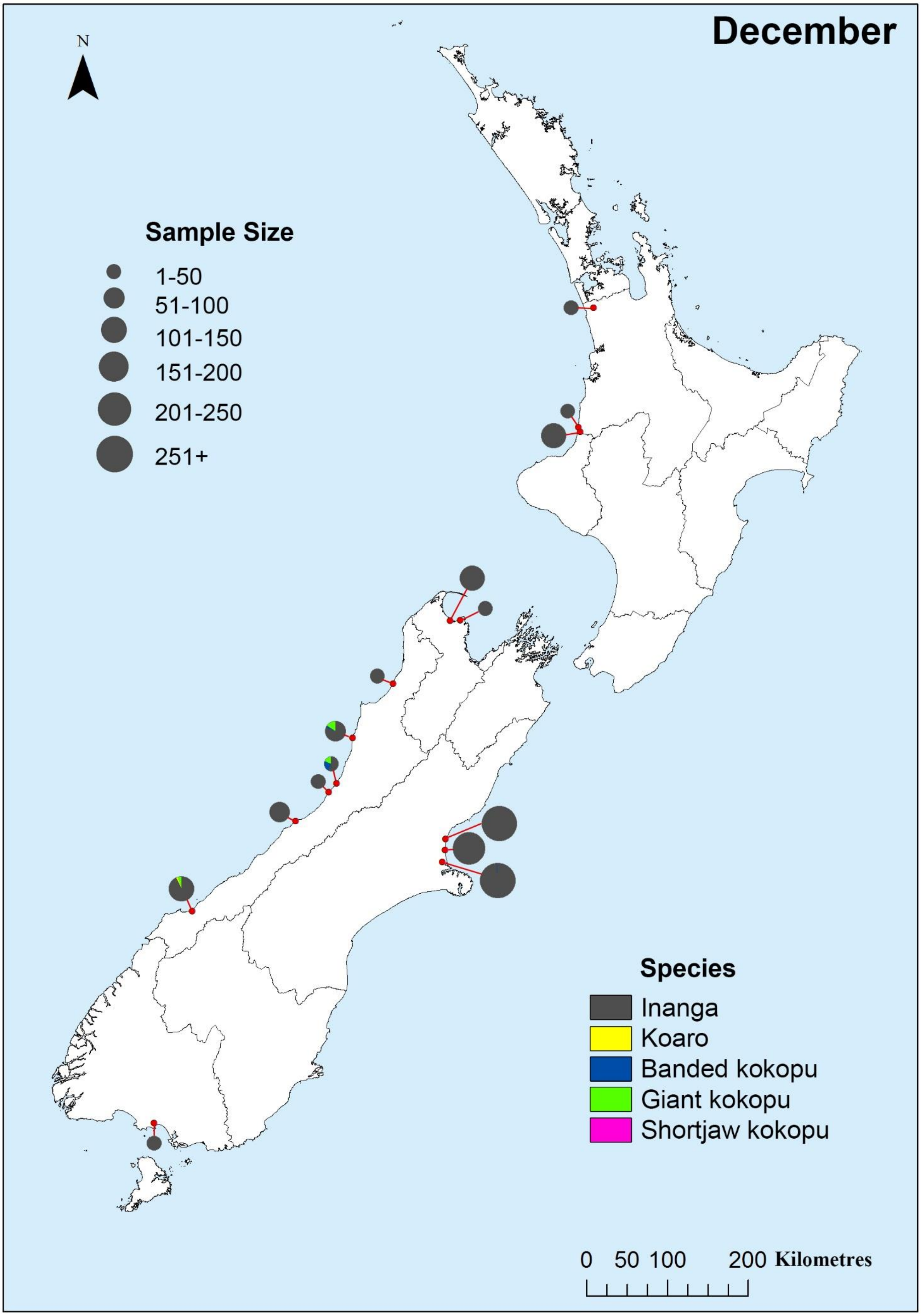


Figure 3.17. Species composition of whitebait samples from 15 rivers during December 2015.

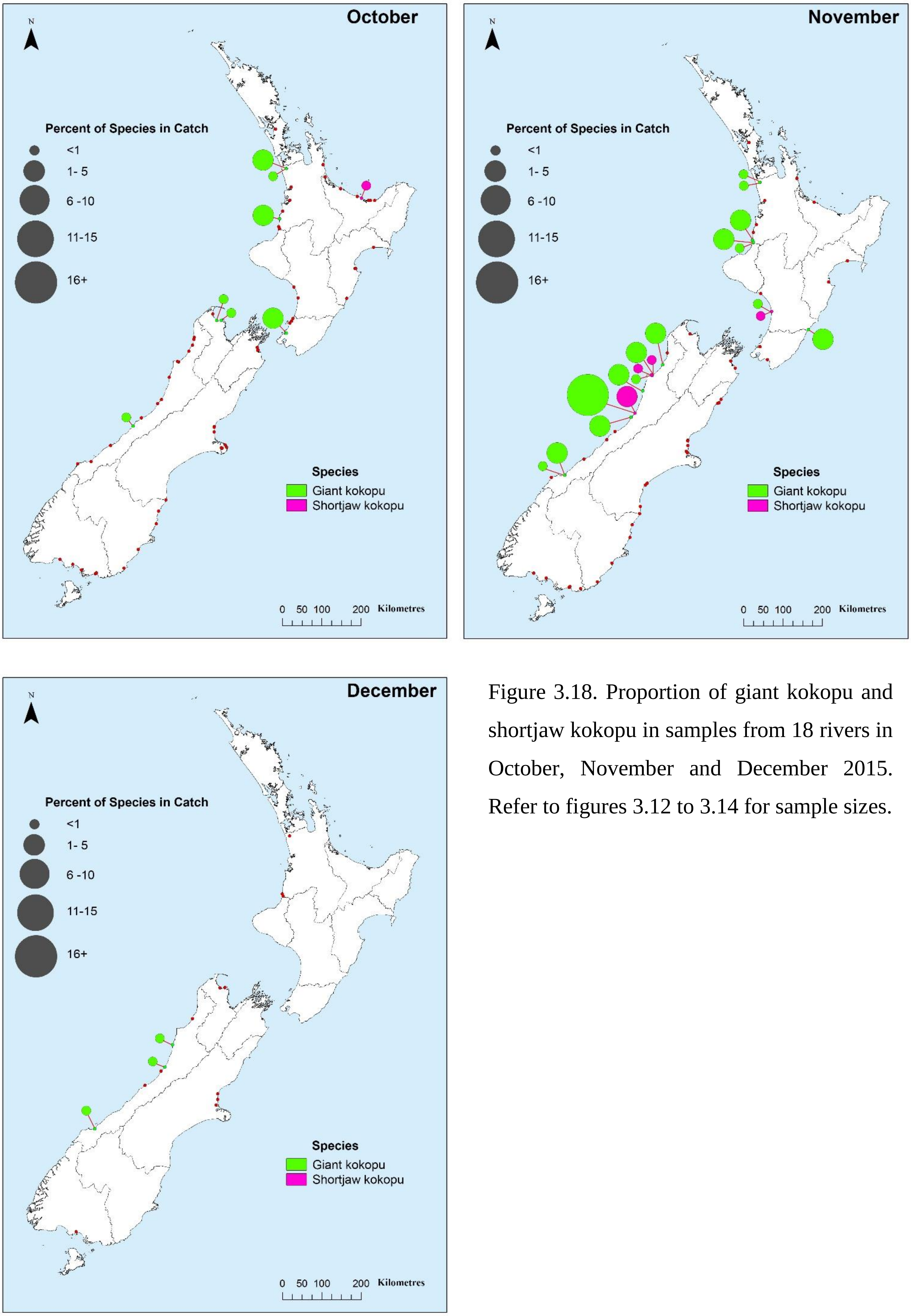


Figure 3.18. Proportion of giant kokopu and shortjaw kokopu in samples from 18 rivers in October, November and December 2015. Refer to figures 3.12 to 3.14 for sample sizes.

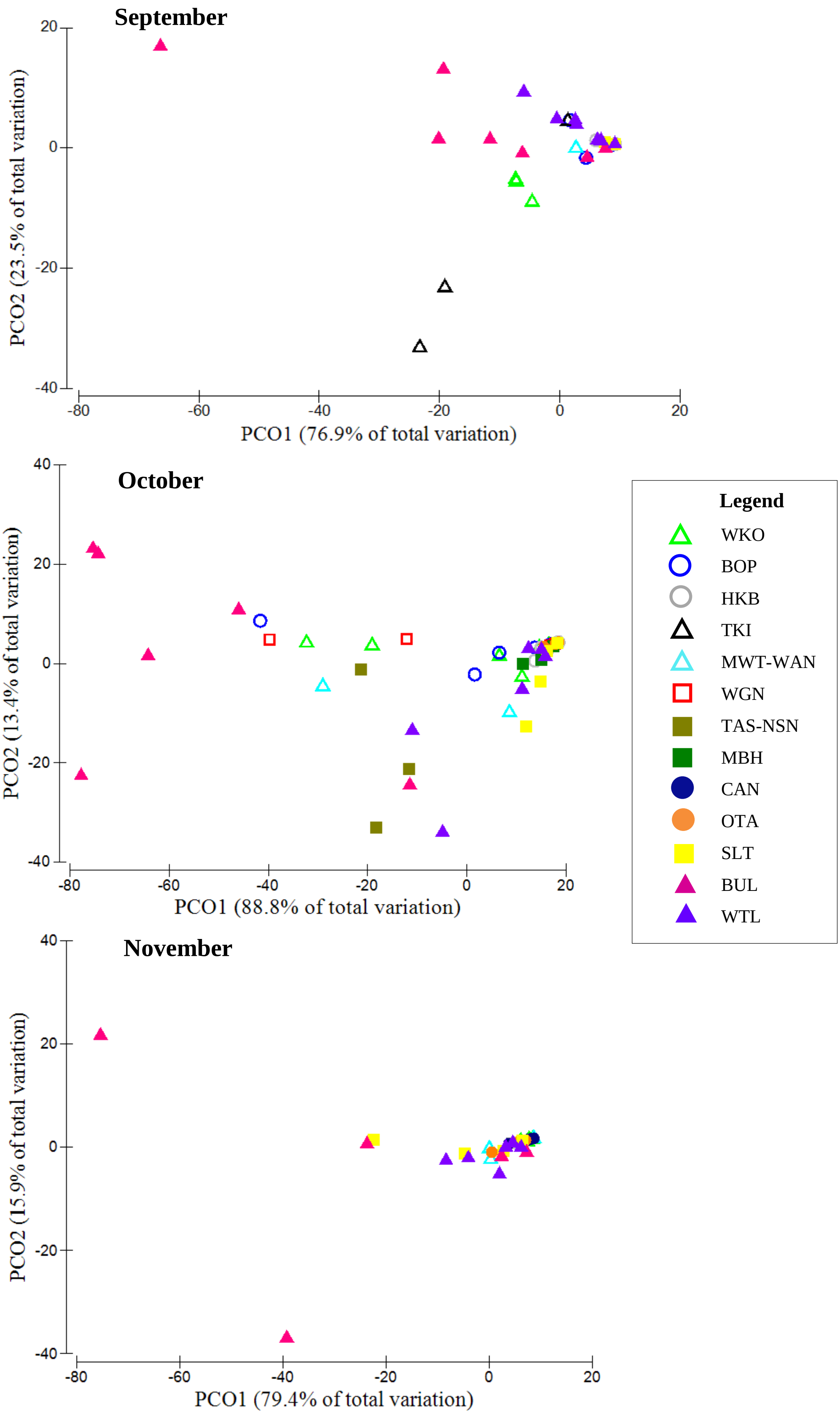


Figure 3.19. PCO plots showing variation in species composition of whitebait samples among rivers in regions in September, October and November. See Fig. 3.10 for region abbreviations.

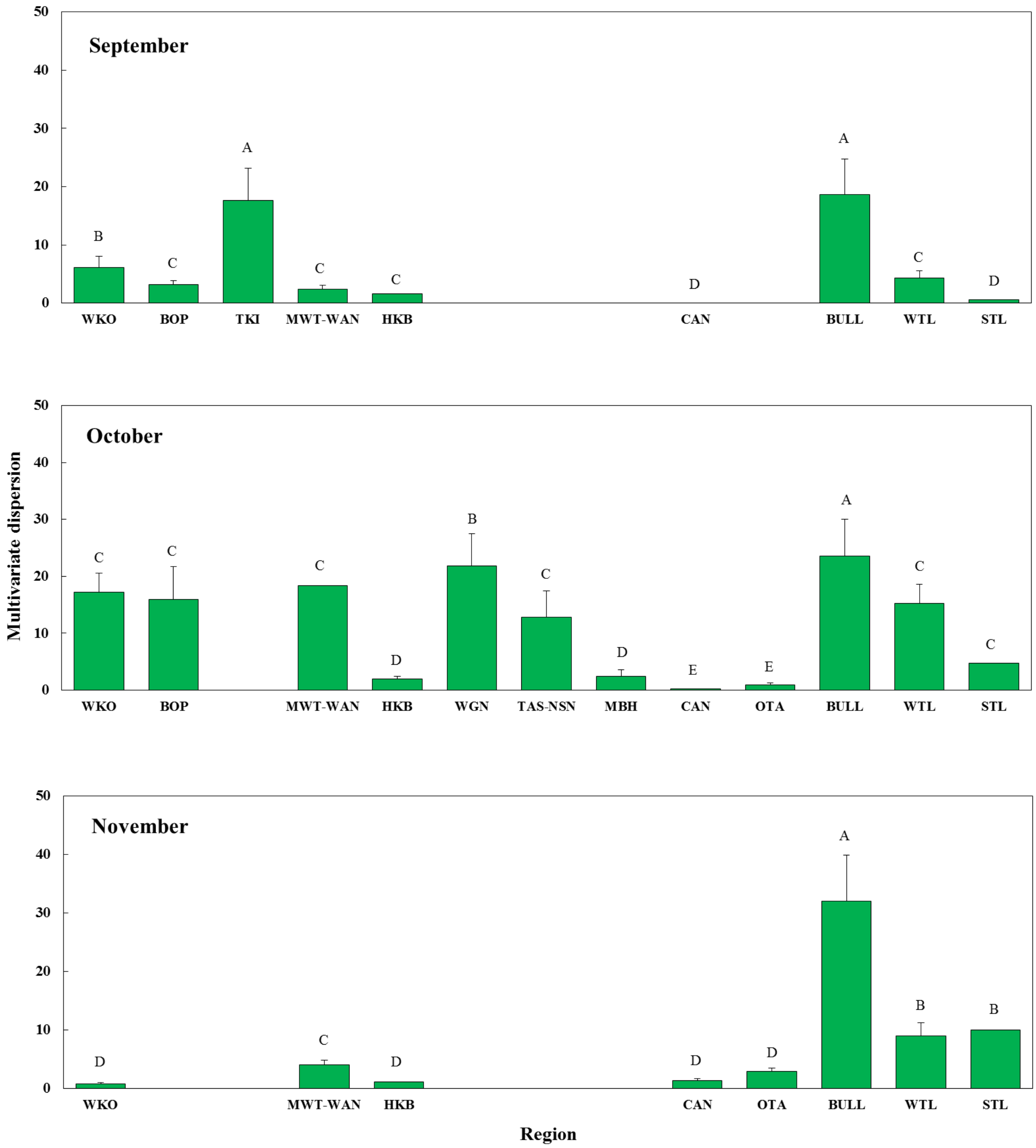


Figure 3.20. Mean values of multivariate dispersion (+SE) showing variability in species composition of whitebait samples within regions in September, October and November (letters A-E show results of Newman-Keuls post hoc test). See Fig. 3.10 for region abbreviations.

3.3.1.4 Environmental Variables

3.3.1.4.1 Influence of environmental variables on composition

DISTLM analyses showed that forest cover was a significant predictor of whitebait species composition, whereas pasture cover and catchment area had little predictive power. Marginal tests showed that forest cover explained 22% of the difference in species composition between regions in September, 23% in October and 11% in November (Table 3.5). On the other hand, pasture explained 6-15% of the difference in species composition between regions across months, and catchment area less than 1-3%. For all months, a model including forest cover as the only predictor was the most appropriate to explain variability in species composition (Table 3.5)

Table 3.5. Summary of DISTLM models with forest cover as predictor of variability in species composition.

Months	Variable	Forest cover SS	Residual SS	df	Pseudo-F	P	R Square
September	Forest cover	2316.9	8033.2	1,36	10.38	<0.01	0.22
October	Forest cover	10042	32997	1,49	14.91	<0.001	0.23
November	Forest cover	1385	10688.4	1,33	4.28	<0.05	0.11

PERMANOVA analyses of whitebait species composition across regions were run in the presence and absence of the co-variable forest cover. In the September analysis, the inclusion of forest cover reduced the region SS by 36.4% and the residual SS by 10.3%. In the October analyses, the inclusion of forest cover reduced the region SS by 33.5% and the residual SS by 1.6% and in November the inclusion of forest cover reduced the region SS by 26.2% and the residual by 2.7%. The differences among regions remained significant in September and October, but not in November (Table 3.6).

Table 3.6. Results of PERMANOVA analyses run in the presence and absence of the co-variable forest cover.

Months	Analysis	Source of variation	SS	df	Pseudo-F	P
September	PERMANOVA	Region	4789.40	8	3.12	<0.05
		Residual	5560.70	29	13.01	<0.001
		Total	10350.00	37		
	PERMANOVA and predictor	Forest Cover	2316.90	1	13.01	<0.001
		Region	3045.80	8	2.14	<0.05
		Residual	4987.50	28		
		Total	10350.00	37		
October	PERMANOVA	Region	29285.00	10	8.52	<0.001
		Residual	13754.00	40		
		Total	43039.00	50		
	PERMANOVA and predictor	Forest Cover	10042.00	1	28.94	<0.001
		Region	19463.00	10	5.61	<0.001
		Residual	13533.00	39		
		Total	43039.00	50		
November	PERMANOVA	Region	4515.00	7	2.30	0.05
		Residual	7558.40	27		
		Total	12073.00	34		
	PERMANOVA and predictor	Forest Cover	1385.00	1	4.89	<0.05
		Region	3330.50	7	1.68	0.13
		Residual	7357.90	26		
		Total	12073.00	34		

3.3.1.4.2 Influence of environmental variables on individual species

A model including forest cover as the only predictor was the most appropriate to explain variability in species composition of each of the three species in all months. In September, October and November the proportion of inanga in whitebait samples was strongly negatively correlated to forest cover, while koaro and banded kokopu proportions were positively correlated with forest cover (Table 3.7).

Regression analyses showed that forest cover was a significant predictor of the species composition of inanga and koaro in all three months, and banded kokopu in September and October (Table 3.7).

Table 3.7. Values of Pearson correlation coefficient and regression results showing the direction and strength of the relationship between forest cover and the proportion of each species in whitebait samples from September, October and November.

Months	**Species**	**Pearson Coefficient**	**Forest cover SS**	**Residual SS**	**df**	**F**	**P**	**R Square**
September	Inanga	-0.510	2583.01	6986.60?	1,35	12.94	<0.001	0.270
	Koaro	0.404	841.07	4416.53	1,35	6.67	<0.05	0.160
	Banded kokopu	0.346	476.20	2960.09	1,35	5.63	<0.05	0.139
October	Inanga	-0.530	11255.39	28961.34	1,48	18.65	<0.001	0.280
	Koaro	0.290	392.78	4275.10	1,48	4.41	<0.05	0.084
	Banded kokopu	0.480	7411.86	25387.48	1,48	14.01	<0.001	0.226
November	Inanga	-0.375	1607.54	9839.47	1,33	5.39	<0.05	0.140
	Koaro	0.390	1115.71	6227.67	1,33	5.91	<0.05	0.152
	Banded kokopu	0.090	15.75	2100.62	1,33	0.24	0.62	0.007

Giant kokopu and shortjaw kokopu were observed in samples from rivers with a high presence of forest cover in catchments. Likewise, proportions of koaro and banded kokopu greater than 10% were found in samples from rivers with extensive forest cover in the catchment (Fig. 3.21). However, low proportions of koaro and banded kokopu were also found entering rivers in regions where forest cover was absent (e.g. Canterbury).

Giant kokopu, shortjaw kokopu, koaro and banded kokopu were found to have a strong association with the presence of each species from historical New Zealand Freshwater Fish Database records (Fig. 3.22). The majority of rivers with non-inanga species present in samples had historical records of species-specific observations in those rivers.

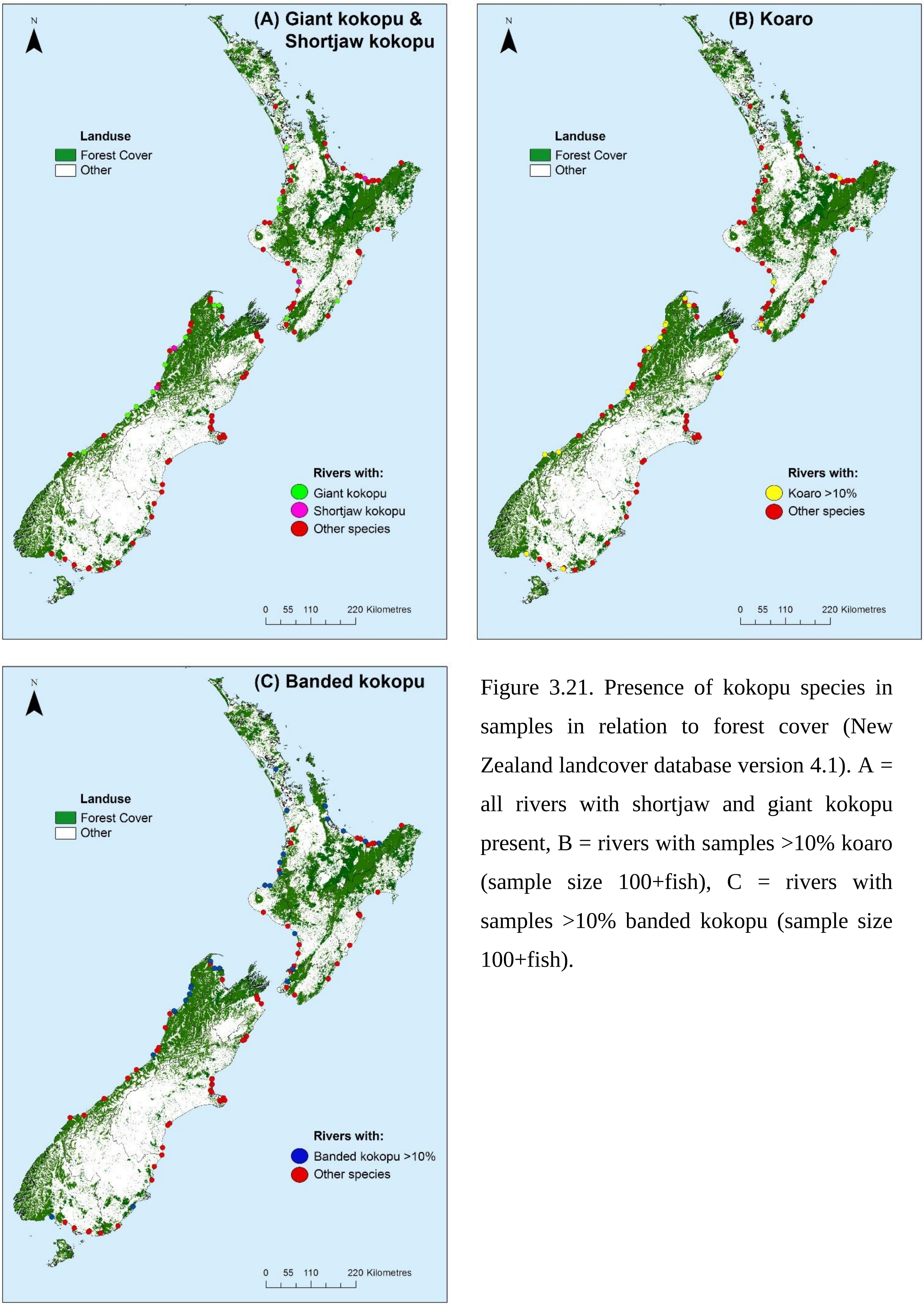


Figure 3.21. Presence of kokopu species in samples in relation to forest cover (New Zealand landcover database version 4.1). A = all rivers with shortjaw and giant kokopu present, B = rivers with samples >10% koaro (sample size 100+fish), C = rivers with samples >10% banded kokopu (sample size 100+fish).

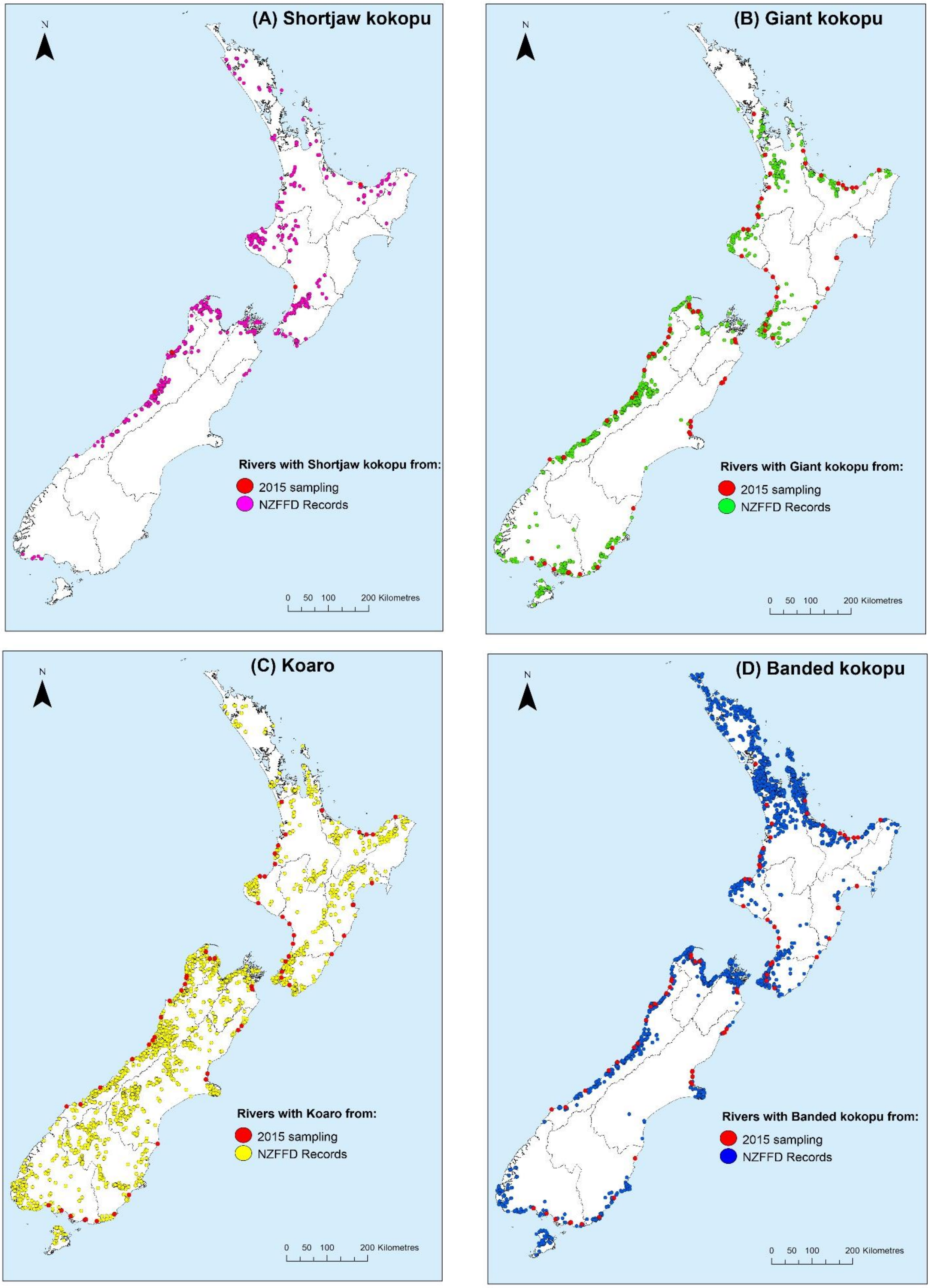


Figure 3.22. Presence of non-inanga whitebait species in samples in relation to species records from the New Zealand Freshwater Fish Database (1964 to 2015). A = rivers with shortjaw kokopu present, B = rivers with giant kokopu present, C = rivers with koaro present, D = rivers with banded kokopu present

3.3.1.5 Non-galaxiid species in samples

Non-galaxiid species were present in many 'whitebait' samples. These included smelt (*Retropinna* sp.), glass eels/elvers of longfin (*Anguilla dieffenbachii*) and shortfin (*A. australis*) eels, juvenile and adult *Gobiomorphus* sp., freshwater shrimps (*Paratya* sp.), yellow-eyed mullet (*Aldrichetta forsteri*), lamprey (*Geotria australis*) and even a juvenile barracuda (*Thyrsites atun*) in one instance.

3.3.1.5.1 Smelt

Smelt were widespread and present in all regions apart from Tasman-Nelson. In some rivers, and at certain times of the year, smelt made up the majority of 'whitebait' sample. At the Waikato River mouth, common smelt (*Retropinna retropinna)* made up 97% of the samples caught throughout the whitebaiting season (Fig. 3.23). Smelt were also present at sites several kilometres upstream, but in smaller proportions and the fish were often at the adult stage, while juveniles were most common at the river mouth.

At the start of December on the Aparima River (Southland) a few individual whitebait were caught amongst several kilograms of smelt. Similarly, on the Kaituna River (Bay of Plenty) smelt were present in 5 of the 9 samples collected during the 2015 survey with smelt making up as much as 84% of some samples in November (Fig. 3.23).

Juvenile and adult bullies were present in rivers in the North and South Islands. *Paratya* shrimp were limited to North Island Rivers. Observations of glass eels, adult eels, lamprey, yellow-eyed mullet, and barracuda were limited to one or few occasions.

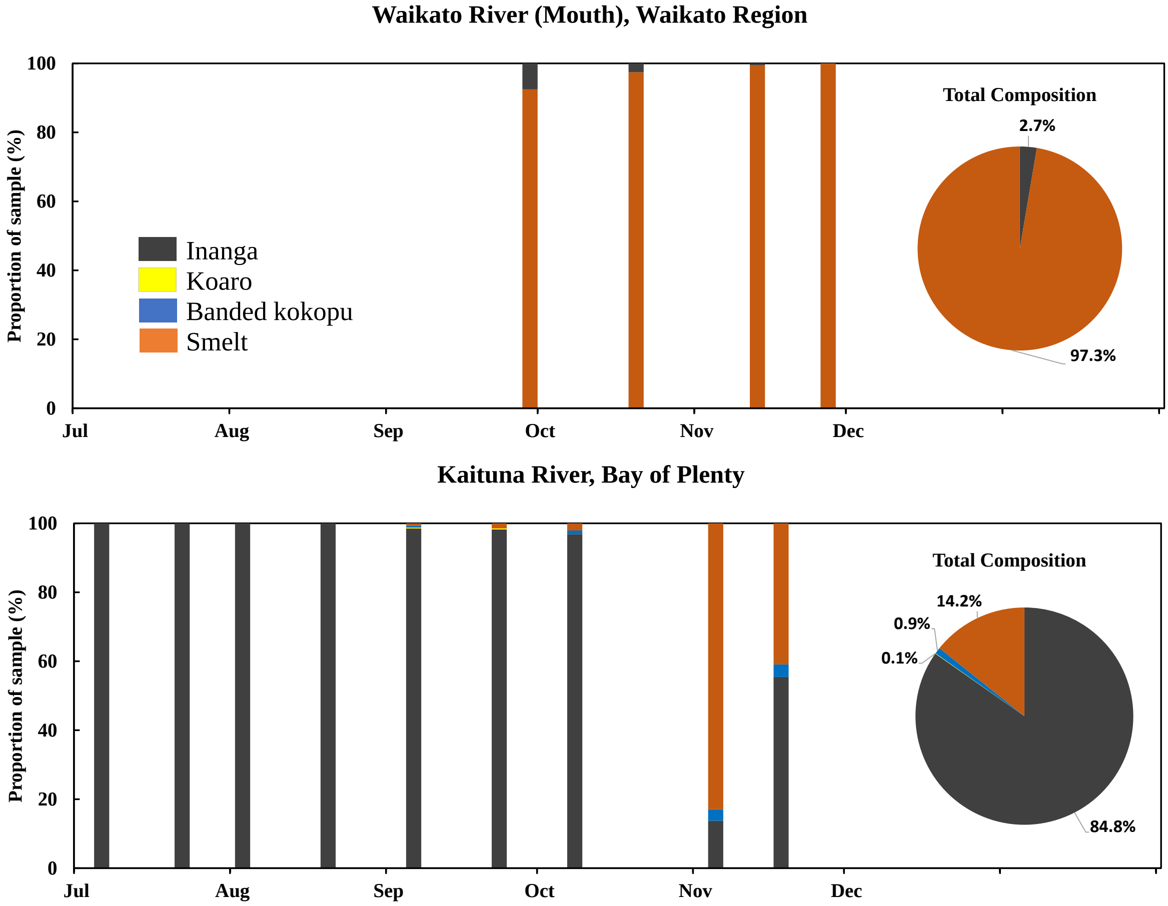


Figure 3.23. Proportional abundance of smelt in 'whitebait' samples from the Waikato River Mouth (Waikato) and Kaituna River (Bay of Plenty) during the 2015 whitebait season.

3.3.2 Morphology

The five species of whitebait differed in length/weight relationships despite substantial overlap (Fig. 3.24). Banded kokopu were found to have the smallest total lengths and wet weights, whereas koaro were found to have the largest. Giant kokopu were intermediate in length between banded kokopu and koaro, and were generally heavier in comparison to their length (plump).

The length/weight relationship of inanga varied greatly with some large and small fish, but generally inanga were lighter/slender in comparison to their length. Of the few shortjaw kokopu observed, they were heavier (very stout) in comparison to their length.

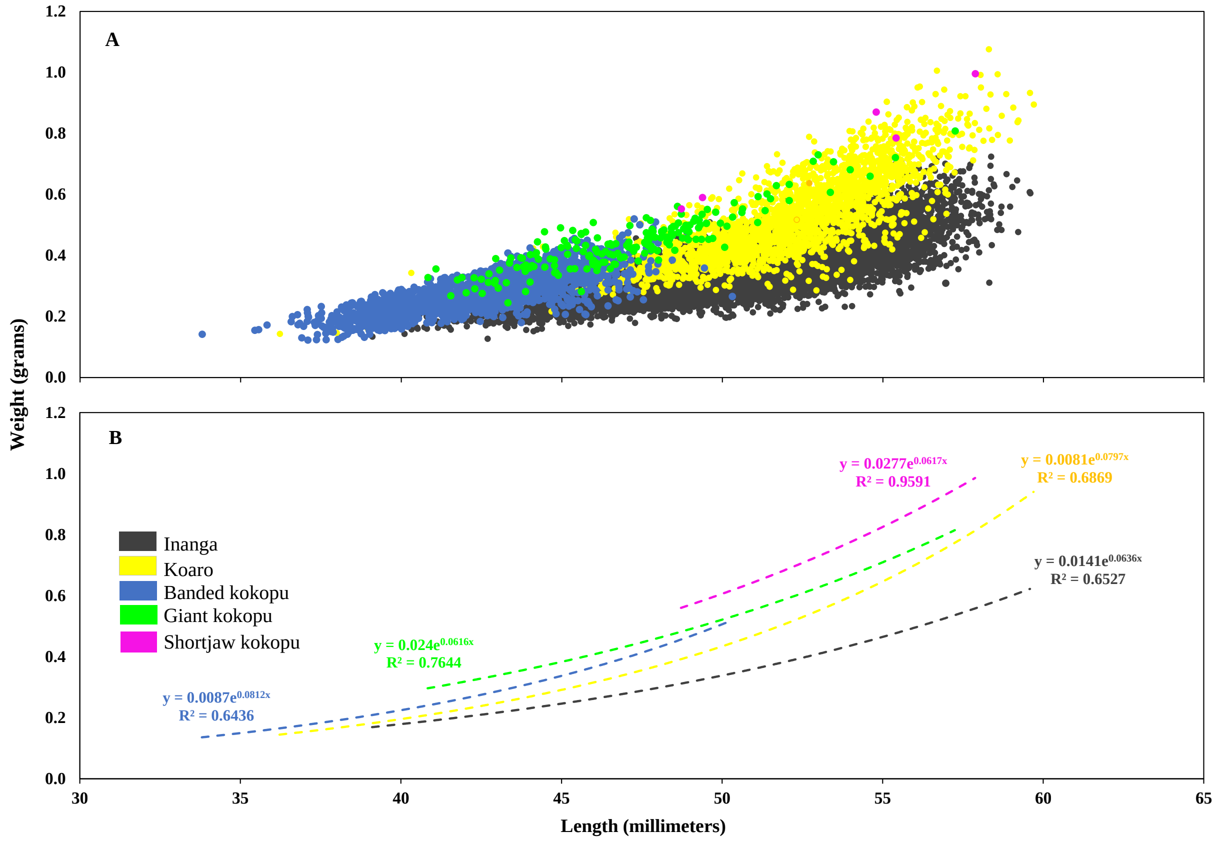


Figure 3.24. Relationship between total length and wet weight of over 17,000 whitebait measured throughout New Zealand during the 2015 study. A = whitebait data points B = trendlines for each species.

The smallest total lengths and wet weights of individuals from all five species were recorded in whitebait samples from the upper North Island (Waikato, Coromandel, and Bay of Plenty; Table 3.8) apart from the lightest inanga which was in a sample from Manawatu-Wanganui (0.127g). The shortest and lightest of any whitebait species were banded kokopu (33.8mm) from samples from the Kaituna River (Bay of Plenty), and (0.123g) Wentworth River (Coromandel).

The largest and heaviest koaro, banded kokopu, giant kokopu and shortjaw kokopu were recorded in whitebait samples from Buller. However, the longest and heaviest inanga were from the Taramakau (Westland; 59.6mm) and Aparima (Southland; 0.724g) Rivers.

The smallest body depth of inanga, koaro and banded kokopu were recorded in samples from Westland, but for giant kokopu and shortjaw kokopu they were from Waikato and Bay of Plenty. In contrast, the largest body depths of whitebait species were recorded in Buller and also Westland.

Table 3.8. Ranges of total length, wet weight and body depth of five galaxiid species in whitebait samples from throughout New Zealand in 2015.

Species			**Morphological measurement**	**Region**	**River**	**Date**
Inanga *(G. maculatus)*	Total Length (mm)	Minimum	39.1	Coromandel	Wentworth	07/11/15
		Maximum	59.6	Westland	Taramakau	14/09/15
	Wet Weight (g)	Minimum	0.127	Manawatu	Rangitikei	09/09/15
		Maximum	0.724	Southland	Aparima	15/10/15
	Body Depth (mm)	Minimum	2.4	Westland	Waiatoto	07/10/15
		Maximum	6.6	Westland/Buller	Hokitika/Karamea	14/11/15, 14/11/15
Koaro *(G. brevipinnis)*	Total Length (mm)	Minimum	36.2	Bay of Plenty	Whakatane	01/09/15
		Maximum	59.7	Buller	Buller	18/11/15
	Wet Weight (g)	Minimum	0.143	Bay of Plenty	Whakatane	01/09/15
		Maximum	1.076	Buller	Buller	18/11/15
	Body Depth (mm)	Minimum	2.6	Westland	Waiatoto	07/10/15
		Maximum	7.2	Buller	Mokihinui	11/10/15
Banded kokopu *(G. fasciatus)*	Total Length (mm)	Minimum	33.8	Bay of Plenty	Kaituna	05/11/15
		Maximum	48.5	Buller	Little Wanganui	24/09/15
	Wet Weight (g)	Minimum	0.123	Coromandel	Wentworth	07/10/15
		Maximum	0.520	Buller	Karamea	06/10/15
	Body Depth (mm)	Minimum	2.0	Westland	Waiatoto	07/10/15
		Maximum	5.8	Buller	Karamea	14/11/15
Giant kokopu *(G. argenteus)*	Total Length (mm)	Minimum	40.8	Waikato	Waikato	29/10/15
		Maximum	55.4	Buller	Mokihinui	17/11/15
	Wet Weight (g)	Minimum	0.245	Waikato	Waikato	04/11/15
		Maximum	0.808	Buller	Buller	18/11/15
	Body Depth (mm)	Minimum	4.3	Waikato	Waikato	29/10/15
		Maximum	6.6	Westland	Waiatoto	13/11/15
Shortjaw kokopu *(G. postvectis)*	Total Length (mm)	Minimum	48.7	Bay of Plenty	Whakatane	05/10/15
		Maximum	57.9	Buller	Orowaiti	09/11/15
	Wet Weight (g)	Minimum	0.553	Bay of Plenty	Whakatane	05/10/15
		Maximum	0.996	Buller	Orowaiti	09/11/15
	Body Depth (mm)	Minimum	6.0	Bay of Plenty	Whakatane	05/10/15
		Maximum	7.4	Buller	Orowaiti	09/11/15

3.3.2.1 Whitebait length

The total length of inanga, koaro and banded kokopu varied among regions and among rivers within regions in September, October and November (Tables 3.9 & 3.10; Fig. 3.25, 3.28, & 3.31). However, the total length of giant kokopu differed among rivers within regions, but not among regions (Fig. 3.34).

Across all species, whitebait in North Island regions were generally smaller than those in South Island regions. The smallest mean lengths were recorded for all species in the Bay of Plenty and Coromandel and the longest in Buller and Westland. In October, the mean total length of inanga in Bay of Plenty was 48.0mm compared with 53.5mm in Buller (Fig. 3.25). Similarly, the mean total length of koaro in Waikato in October was 49.5mm and 54.1mm in Buller. In September, banded kokopu averaged 42mm in Waikato and 46mm in Buller (Fig. 3.23). Across all months, giant kokopu averaged 44.4mm in total length in Waikato and 48.5mm in Buller (Fig. 3.31).

Regions with larger geographical distances between them were found to vary more in total length compared to regions with smaller geographical distances. For example, the differences seen in mean length of inanga in September between Bay of Plenty (48.0mm) and Hawkes Bay (51.0mm) (3mm difference) (ca.130 km apart) were more similar than differences between Bay of Plenty and Westland (54.2mm) (6.2mm difference) (ca. 800km apart) (Fig 3.25).

There were significant differences in mean total lengths between rivers in regions. In Canterbury during November, the mean total length of inanga in Lyell Creek was 52.8mm and only 49.7mm on the Ashley River. Similarly, in November in Southland the mean length of koaro was 50.5mm on the Mataura River and 54.0mm on the Waiau River (Fig. 3.25 & 3.28).

3.3.2.2 Whitebait body depth

The body depth of whitebait species showed similar patterns to those seen with total length. The smallest mean body depths were recorded for all four species in the Upper North Island (Waikato, Bay of Plenty) and the largest mean body depths in Buller, Westland and Southland (Fig. 3.26, 3.29, 3.32 & 3.34).

Body depth varied among regions and among rivers within regions and these differences also changed through time with different temporal patterns depending on the species examined (Tables 3.9 & 3.10).

In Westland during October the mean body depth of koaro was much larger on the Hokitika River (5.7mm) compared to the Waiatoto River (4.5mm) (Fig. 3.29). In Buller during November the mean body depth of banded kokopu was 5.2mm on the Karamea River compared to 4.3mm on the Buller River (Fig. 3.32). There were many similarities between rivers within regions. For example, inanga in September in Bay of Plenty were similar between rivers with the Mataura, Oreti, Waiau and Aparima Rivers mean body depths between 4.8-4.9mm. Similarly, banded kokopu in November in Buller ranged from 4.7-4.8mm on the Mokihinui, Oparara, Karamea, Orowaiti, Karamea and Buller Rivers.

For inanga there were significant differences in body depth between regions in September, but not in October and November. In September, the mean body depth for inanga in Buller (5.4mm) and Westland (5.3mm) were very different to Hawkes Bay (4.6mm), Bay of plenty (4.7mm), and Waikato (4.7mm). Whereas in November, inanga in Marlborough, Hawkes Bay, Otago, Manawatu-Wanganui, Southland, Tasman-Nelson, Buller and Bay of Plenty had similar body depths, but those in samples from Westland, Canterbury and Waikato were different (Fig. 3.26).

For koaro significant differences in body depth between regions were observed in September and November but not in October. Banded kokopu showed significant differences in body depth between regions in September and October but not November. There were no significant differences between regions for body depth of giant kokopu (Tables 3.9 & 3.10).

3.3.2.3 <u>Whitebait condition (relative weight)</u>

Whitebait condition varied among rivers within regions for all species in all months apart from koaro in September (Tables 3.9 & 3.10; Fig. 3.27, 3.30, 3.33 & 3.34).

There were significant differences in condition between regions in September and October for inanga and koaro, and in October for banded kokopu (Tables 3.9 & 3.10). For example, in October inanga in Buller were in better condition than those in Otago (Fig. 3.27). In September, koaro in samples from Buller were in better condition than those from Tasman-

Nelson (Fig. 3.30). On the other hand the condition of inanga in November did not vary considerably in Bay of Plenty and Marlborough, and for banded kokopu in September in Taranaki, Waikato and Buller.

Condition varied considerably between rivers within regions. For example, in November in Westland the condition of koaro in the Cascade River was significantly lower than those in a sample from the Wanganui River (Fig. 3.30). Similarly, for inanga in October for Canterbury condition of inanga in Pawsons Stream was significantly lower than those in a sample from Saltwater Creek (Fig. 3.27).

Fine-scale variations in total length, body depth and relative weight across months will be addressed in Chapter 4.

Table 3.9. Summary of results of nested ANOVA analyses testing variations in fish morphology traits across regions and rivers separately for each species in each month. ‘Yes’ = significant. ‘No’ = not significant.

Species	**Month**	**Source of variation**	**Total Length**	**Body Depth**	**Relative Weight**
Inanga ***(G. maculatus)***	**September**	**Regions**	Yes	Yes	Yes
		Rivers (Region)	Yes	Yes	Yes
	October	**Regions**	Yes	No	Yes
		Rivers (Region)	Yes	Yes	Yes
	November	**Regions**	Yes	No	No
		Rivers (Region)	Yes	Yes	Yes
Koaro ***(G. brevipinnis)***	**September**	**Regions**	Yes	Yes	Yes
		Rivers (Region)	Yes	Yes	No
	October	**Regions**	Yes	No	Yes
		Rivers (Region)	Yes	Yes	Yes
	November	**Regions**	Yes	Yes	Yes
		Rivers (Region)	Yes	Yes	Yes
Banded kokopu ***(G. fasciatus)***	**September**	**Regions**	Yes	Yes	No
		Rivers (Region)	Yes	Yes	Yes
	October	**Regions**	Yes	Yes	Yes
		Rivers (Region)	Yes	Yes	Yes
	November	**Regions**	Yes	No	No
		Rivers (Region)	Yes	Yes	Yes
Giant kokopu ***(G. argenteus)***	**All Months**	**Regions**	No	No	No
		Rivers (Region)	Yes	Yes	Yes

Table 3.10. Results of nested ANOVA analyses testing variations in fish morphology traits across regions and rivers separately for each species in each month.

Species	Characteristic	Month	Source of variation	SS	df	F	P
Inanga ***(G. maculatus)***	**Total length (mm)**	**September**	**Regions**	6952	10	40.5	<0.001
			Rivers (Region)	722	37	7.2	<0.001
		October	**Regions**	5858	11	19.4	<0.001
			Rivers (Region)	1439	48	10.5	<0.001
		November	**Regions**	13005	10	40.3	<0.001
			Rivers (Region)	1405	36	10.7	<0.001
	Body Depth (mm)	**September**	**Regions**	147.34	10	14.65	<0.001
			Rivers (Region)	38.19	35	11.74	<0.001
		October	**Regions**	140182.1	11	0.81997	0.62
			Rivers	820646.6	48	73.81732	<0.001
		November	**Regions**	21072.8	10	0.40762	0.93
			Rivers (Region)	228618.0	36	37.20677	<0.001
	Relative Weight	**September**	**Regions**	59367	10	3.271	<0.01
			Rivers (Region)	77679	37	25.343	<0.001
		October	**Regions**	134768	11	4.468	<0.001
			Rivers (Region)	144564	48	33.977	<0.001
		November	**Regions**	52061	10	1.521	0.17
			Rivers (Region)	151395	36	39.601	<0.001
Koaro ***(G. brevipinnis)***	**Total length (mm)**	**September**	**Regions**	607.4	4	17.61	<0.001
			Rivers (Region)	191.1	14	5.81	<0.001
		October	**Regions**	2212.4	8	21.64	<0.001
			Rivers (Region)	255.1	16	5.73	<0.001
		November	**Regions**	810.0	4	7.15	<0.01
			Rivers (Region)	628.6	11	22.97	<0.001
	Body Depth (mm)	**September**	**Regions**	26.680	4	10.796	<0.001
			Rivers (Region)	13.405	13	11.130	<0.001
		October	**Regions**	57.903	8	1.883	0.13
			Rivers (Region)	76.040	16	13.263	<0.001
		November	**Regions**	42.351	4	8.618	<0.01
			Rivers (Region)	26.068	11	18.256	<0.001
	Relative Weight	**September**	**Regions**	5135	4	1.949	0.15
			Rivers (Region)	15950	14	19.453	<0.001
		October	**Regions**	50901	8	4.163	<0.01
			Rivers (Region)	31886	16	22.353	<0.001
		November	**Regions**	30544	4	4.275	<0.05

			Rivers (Region)	40498	11	43.052	<0.001
Banded kokopu ***(G. fasciatus)***	**Total length (mm)**	**September**	**Regions**	340.9	2	10.57	<0.01
			Rivers (Region)	130.4	8	15.86	<0.001
		October	**Regions**	1287.5	7	18.1	<0.001
			Rivers (Region)	348.0	25	14.2	<0.001
		November	**Regions**	1457.8	7	19.17	<0.001
			Rivers (Region)	158.7	13	7.43	<0.001
	Body Depth (mm)	**September**	**Regions**	16.618	2	6.386	<0.05
			Rivers (Region)	7.684	7	24.454	<0.001
		October	**Regions**	44.523	7	6.26	<0.001
			Rivers (Region)	32.935	24	28.11	<0.001
		November	**Regions**	17.041	7	2.202	0.11
			Rivers (Region)	14.400	12	18.472	<0.001
	Relative Weight	**September**	**Regions**	5108	2	2.210	0.17
			Rivers (Region)	9346	8	15.847	<0.001
		October	**Regions**	31871	7	4.463	<0.01
			Rivers (Region)	35086	25	18.501	<0.001
		November	**Regions**	11490	7	0.706	0.67
			Rivers (Region)	36636	13	35.584	<0.001
Giant kokopu ***(G. argenteus)***	**Total length (mm)**	**All Months**	**Regions**	176.3	2	1.783	0.28
			Rivers (Region)	215.7	4	28.024	<0.001
	Body Depth (mm)	**All Months**	**Regions**	1.324	2	1.282	0.37
			Rivers (Region)	2.232	4	5.831	<0.001
	Relative Weight	**All Months**	**Regions**	0.0126	2	0.65	0.57
			Rivers (Region)	0.0420	4	11.99	<0.001

Inanga – total length

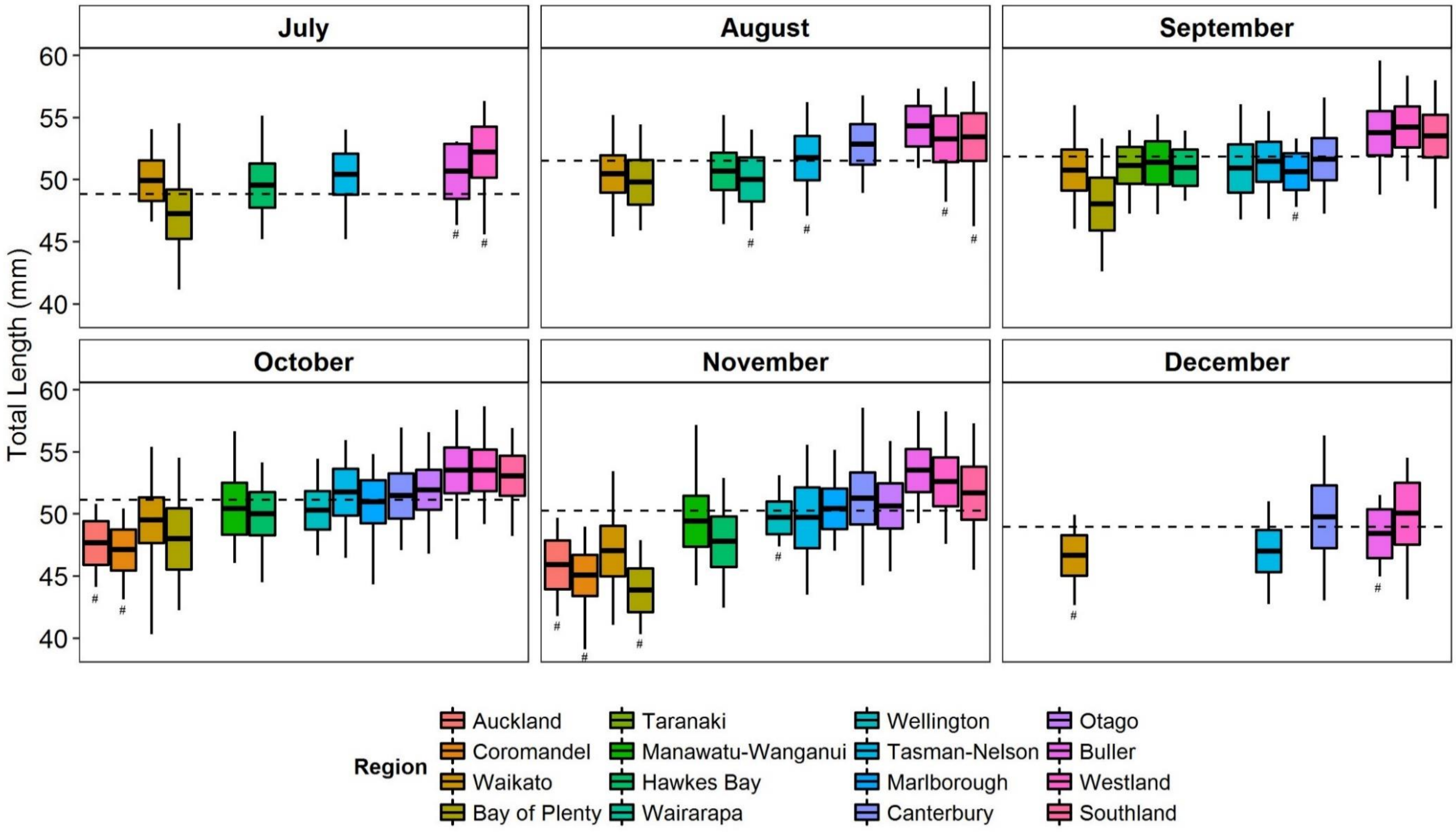


Figure 3.25. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of inanga total length from July to December. The dotted line represents the monthly mean total length across all regions. # = regions excluded from statistical analysis because only one river with more than 10 inanga was sampled.

Inanga – body depth

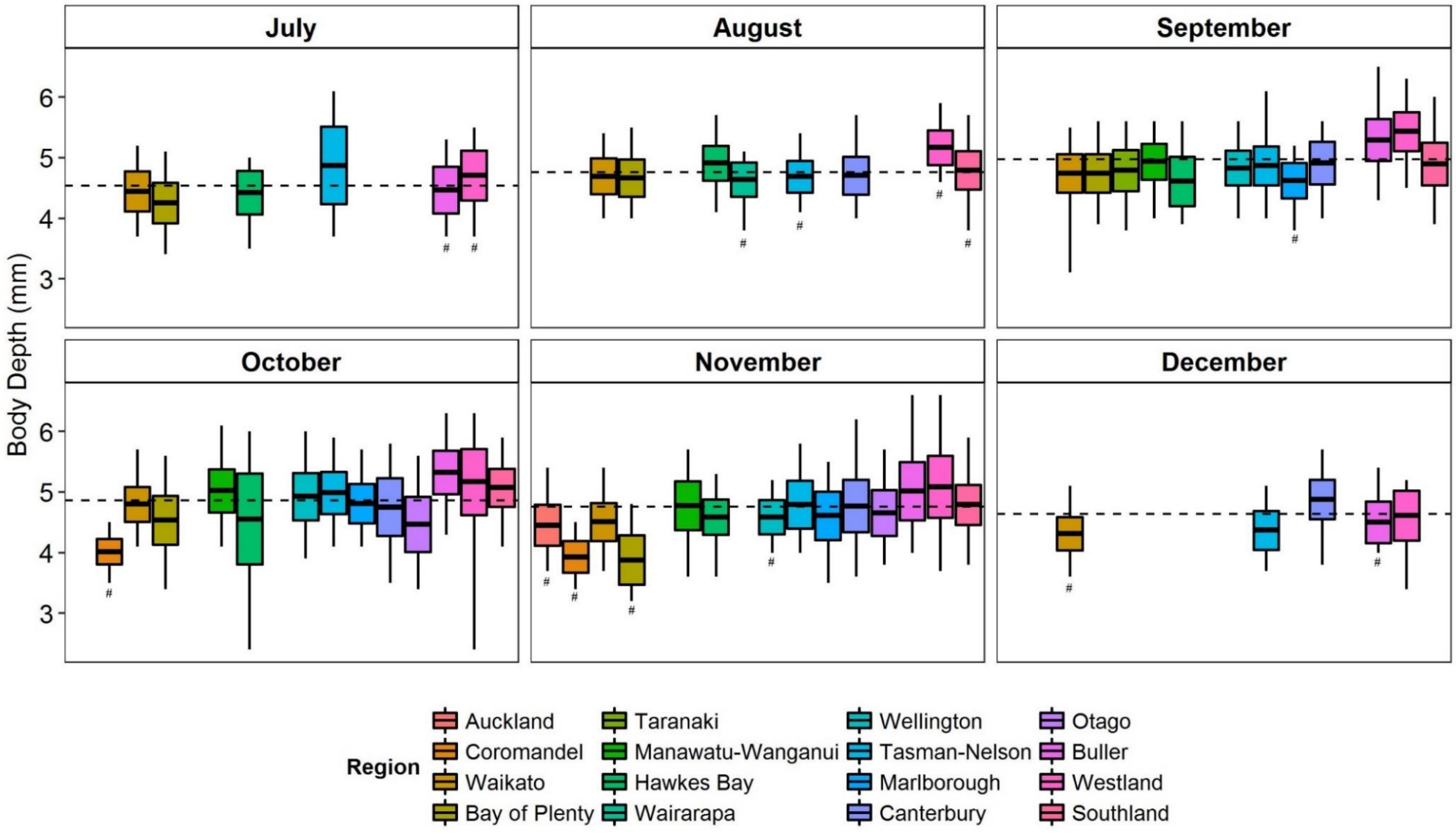


Figure 3.26. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of inanga body depth from July to December. The dotted line represents the monthly mean body depth across all regions. # = regions excluded from statistical analysis because only one river with more than 10 inanga was sampled.

Inanga – condition

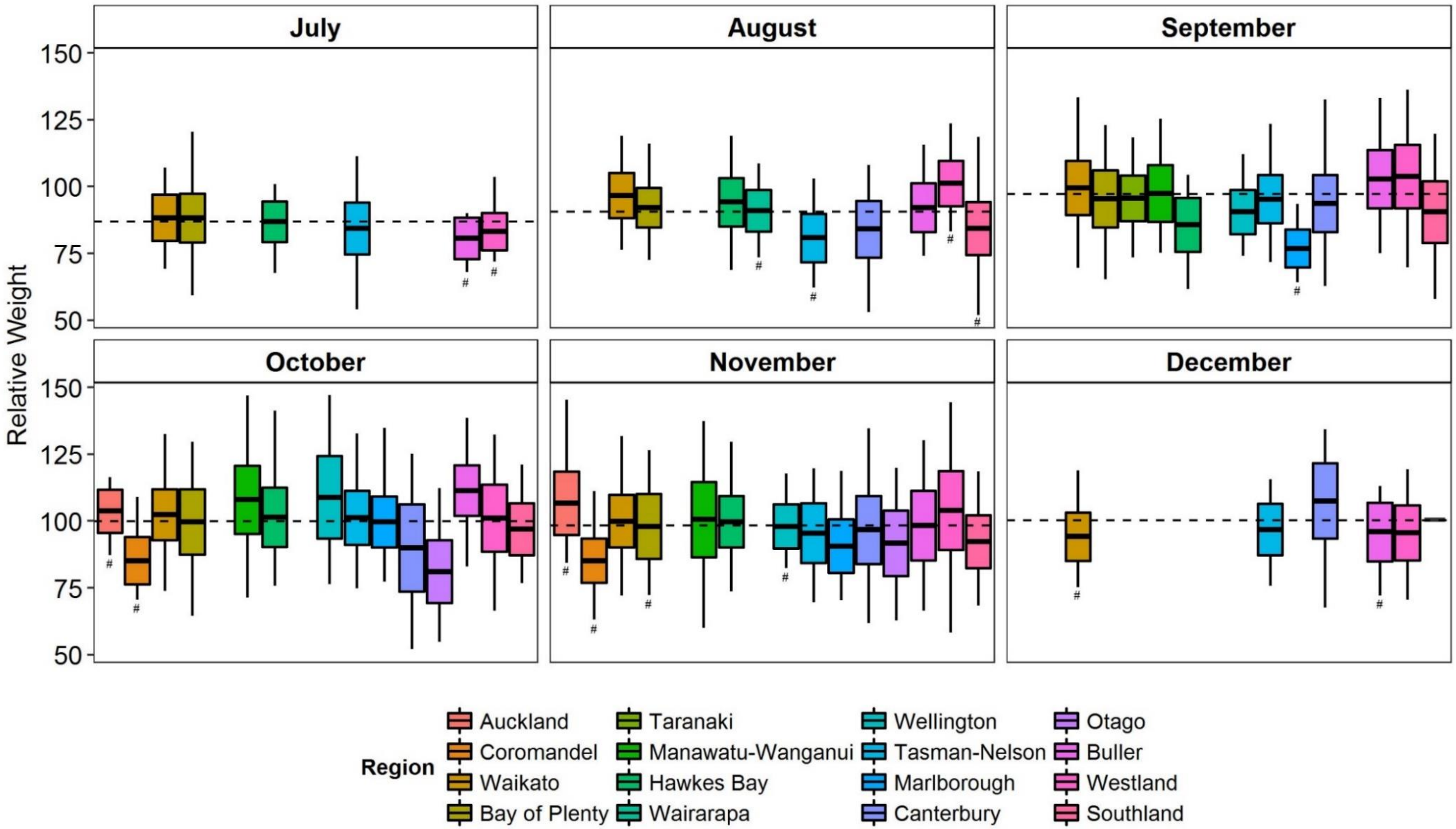


Figure 3.27. Boxplots showing the mean, standard deviation, and minimum/ maximum measurements of inanga condition (relative weight) from July to December. The dotted line represents the monthly mean relative weight across all regions. # = regions excluded from statistical analysis because only one river with more than 10 inanga was sampled.

Koaro – total length

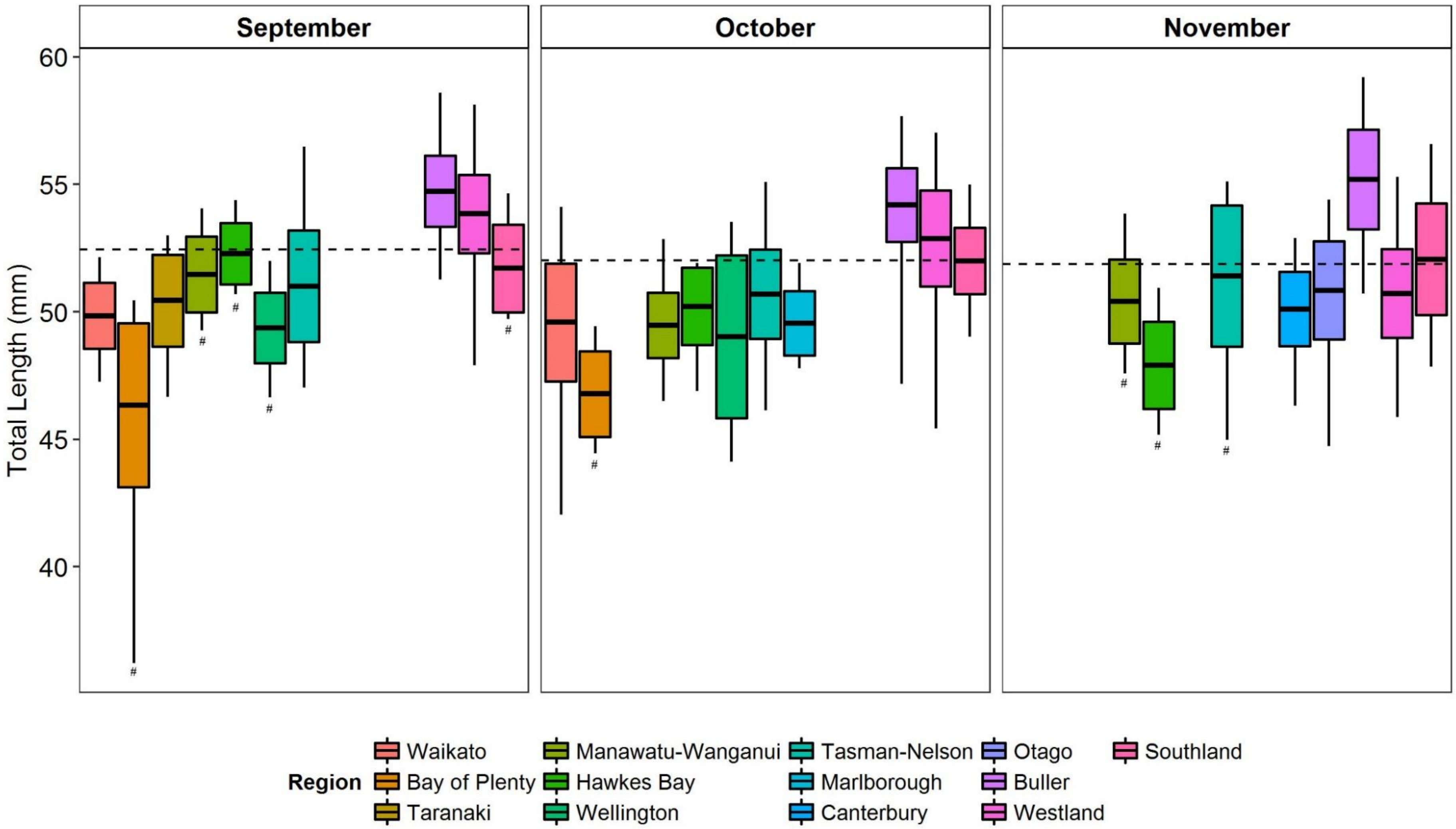


Figure 3.28. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of koaro total length from September to November. The dotted line represents the monthly mean total length across all regions. # = regions excluded from statistical analysis because only one river with more than 5 koaro was sampled.

Koaro – body depth

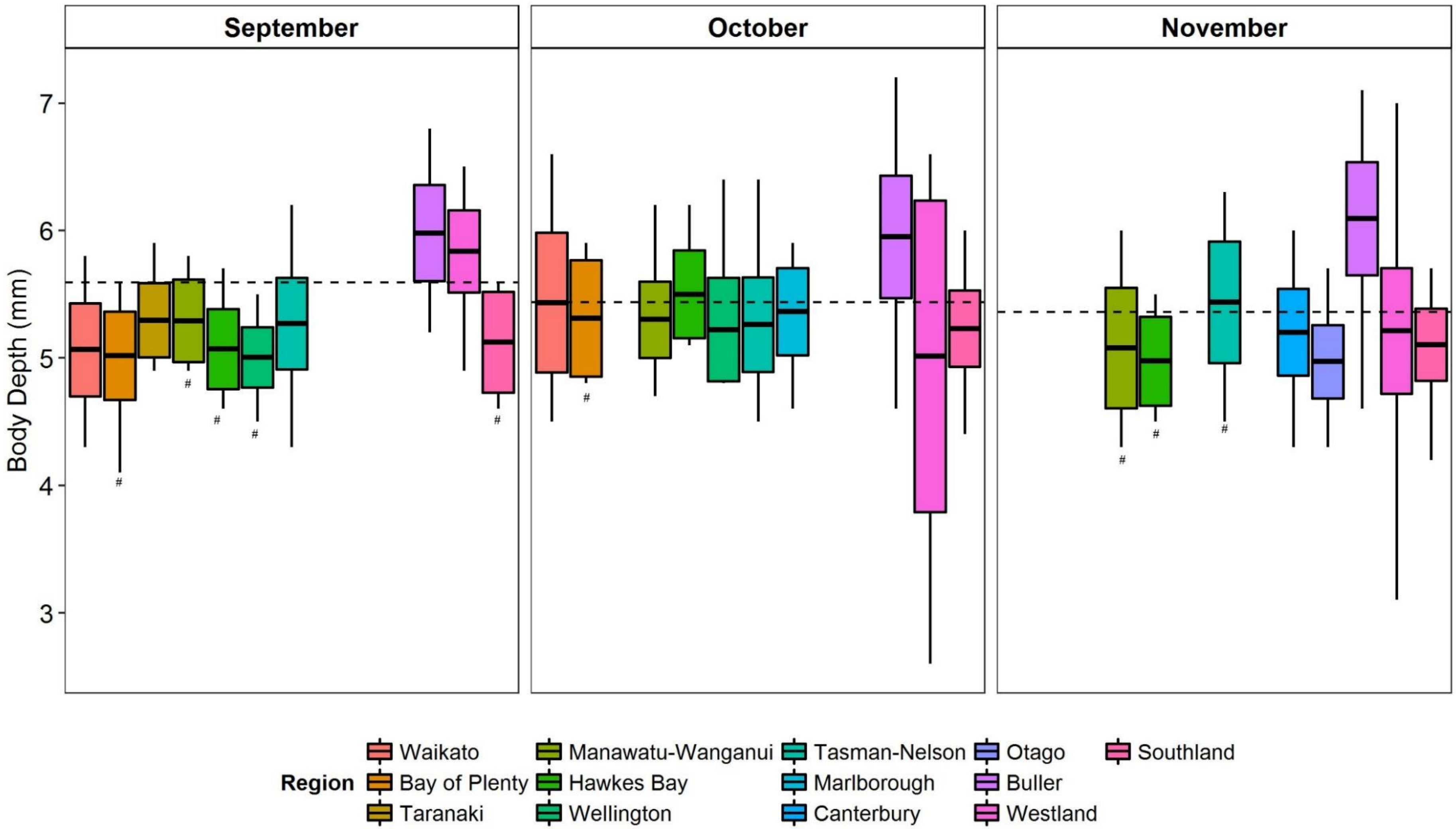


Figure 3.29. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of koaro body depth from September to November. The dotted line represents the monthly mean body depth across all regions. # = regions excluded from statistical analysis because only one river with more than 5 koaro was sampled.

Koaro – condition

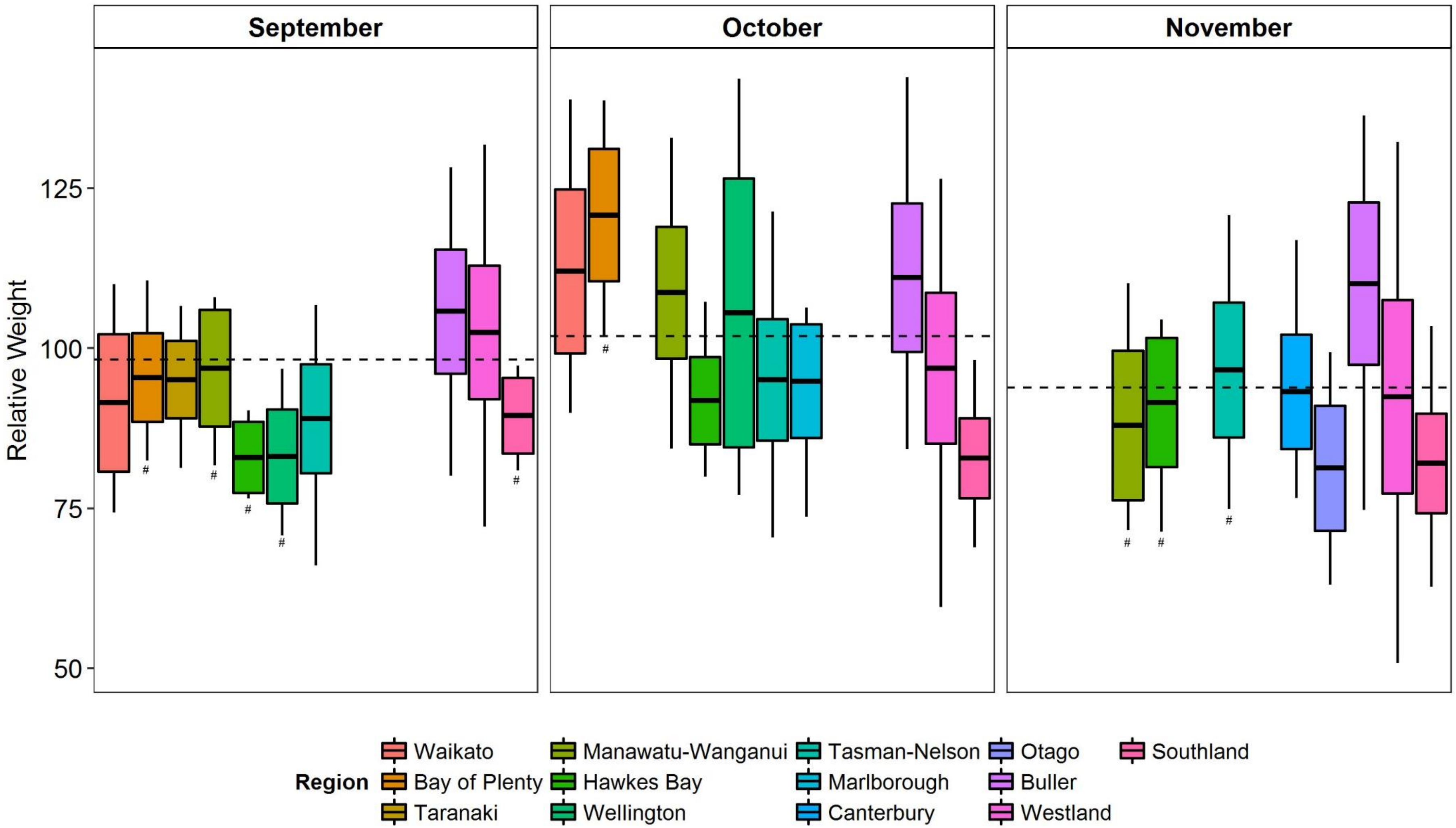


Figure 3.30. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of koaro condition (relative weight) from September to November. The dotted line represents the monthly mean relative weight across all regions. # = regions excluded from statistical analysis because only one river with more than 5 koaro was sampled.

Banded kokopu – total length

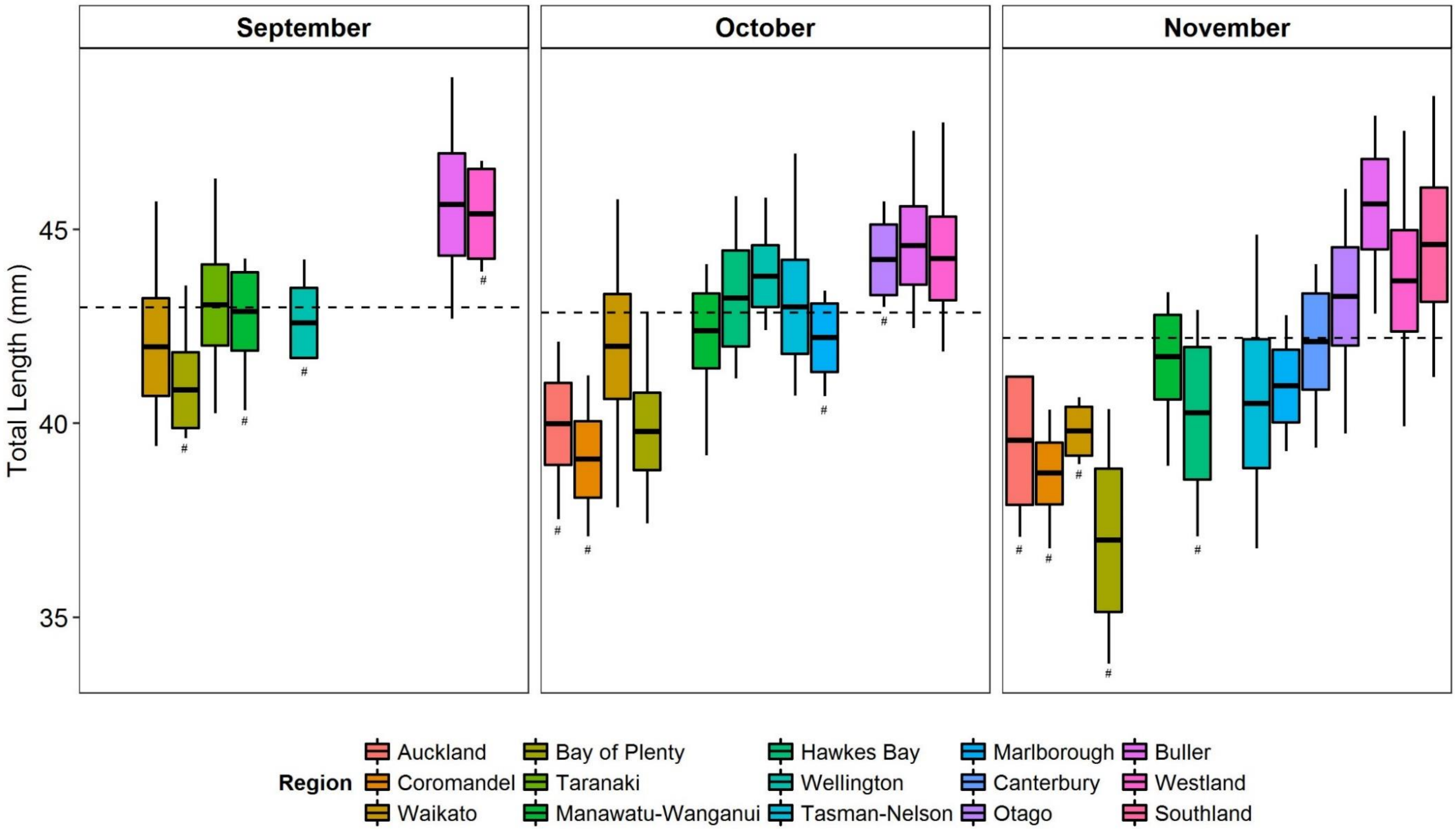


Figure 3.31. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of banded kokopu total length from September to November. The dotted line represents the monthly mean total length across all regions. # = regions excluded from statistical analysis because only one river with more than 5 banded kokopu was sampled.

Banded kokopu – body depth

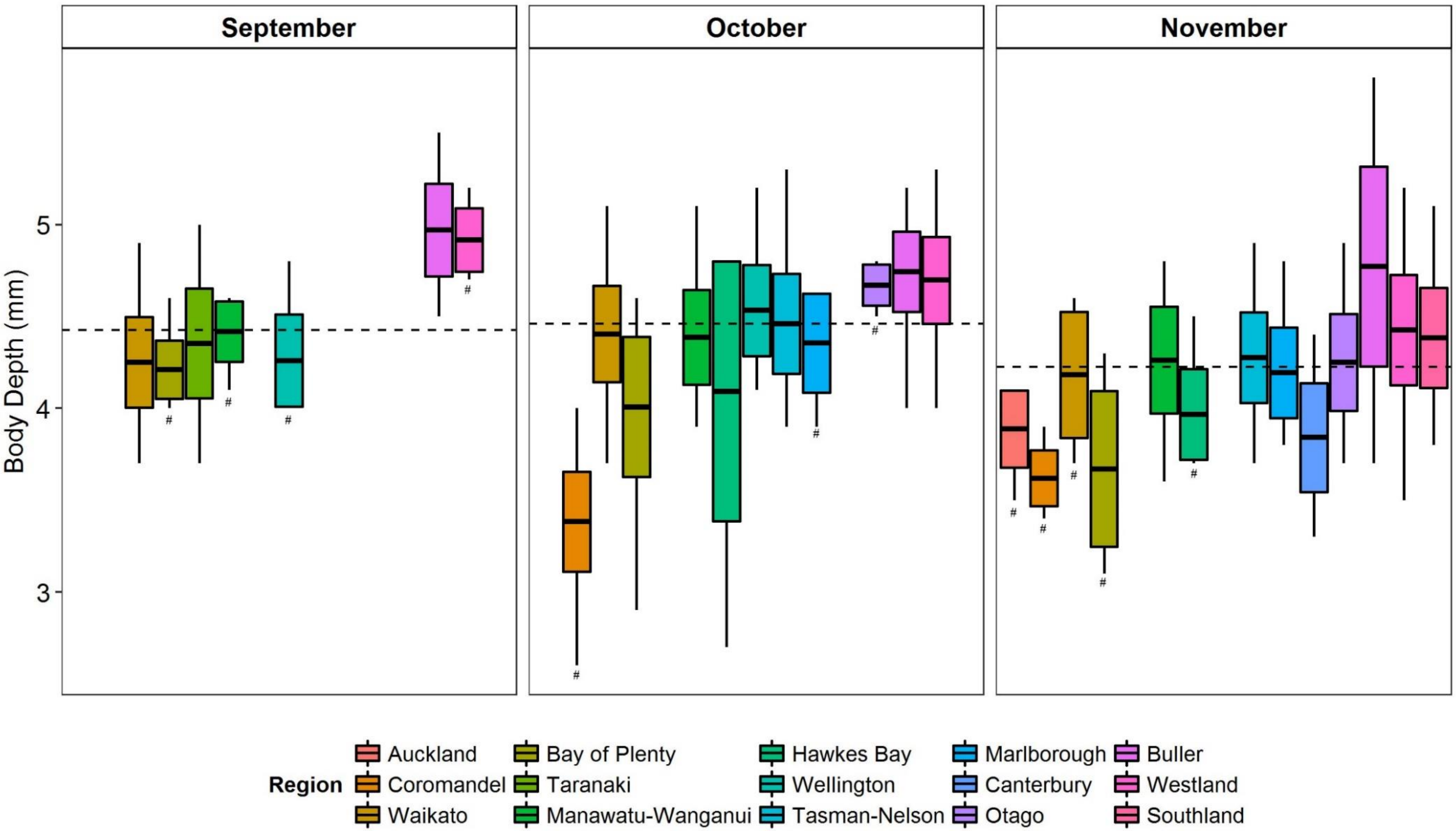


Figure 3.32. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of banded kokopu body depth from September to November. The dotted line represents the monthly mean body depth across all regions. # = regions excluded from statistical analysis because only one river with more than 5 banded kokopu was sampled.

Banded kokopu – condition

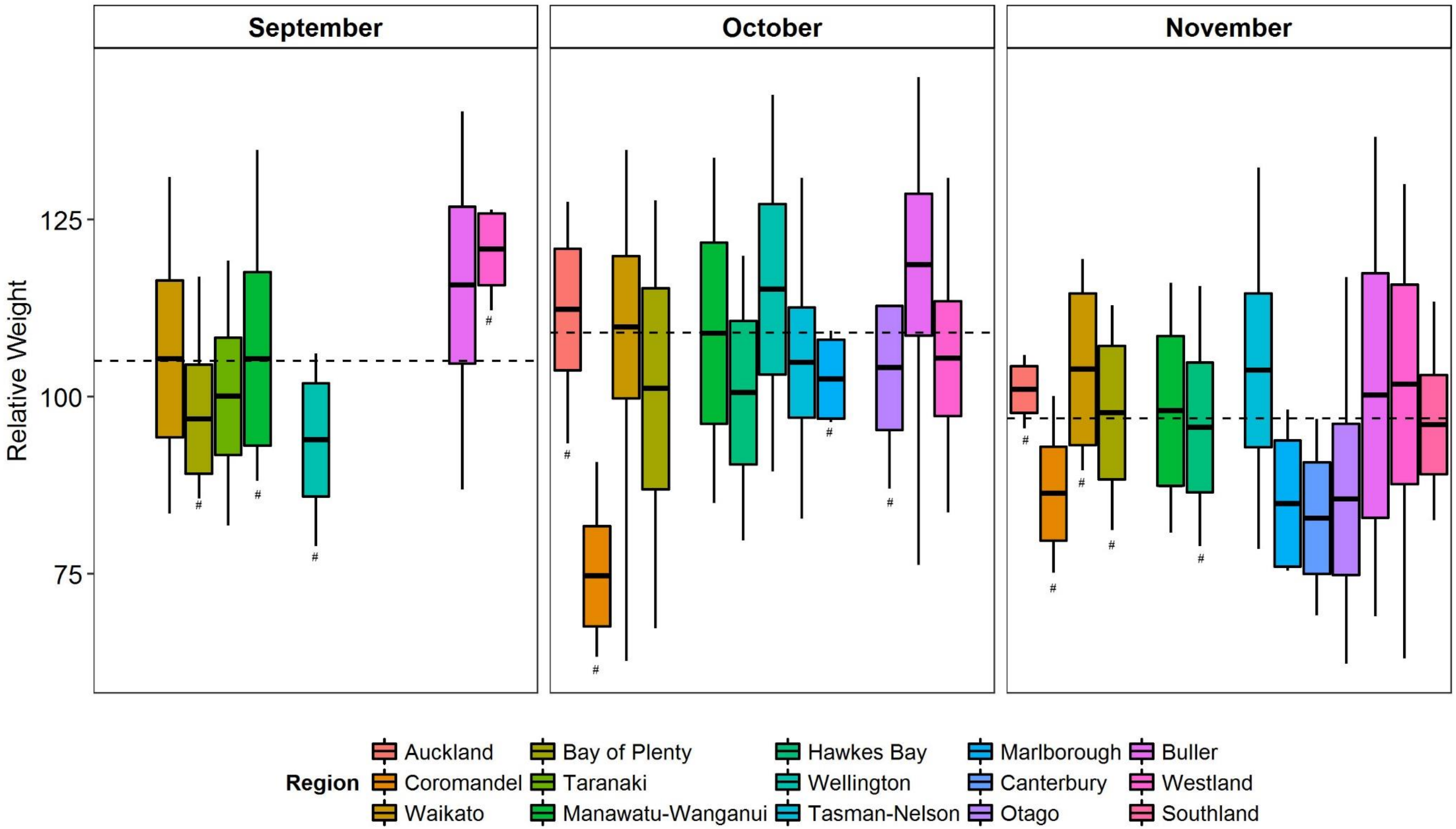


Figure 3.33. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of banded kokopu condition (relative weight) from September to November. The dotted line represents the monthly mean relative weight across all regions. # = regions excluded from statistical analysis because only one river with more than 5 banded kokopu was sampled.

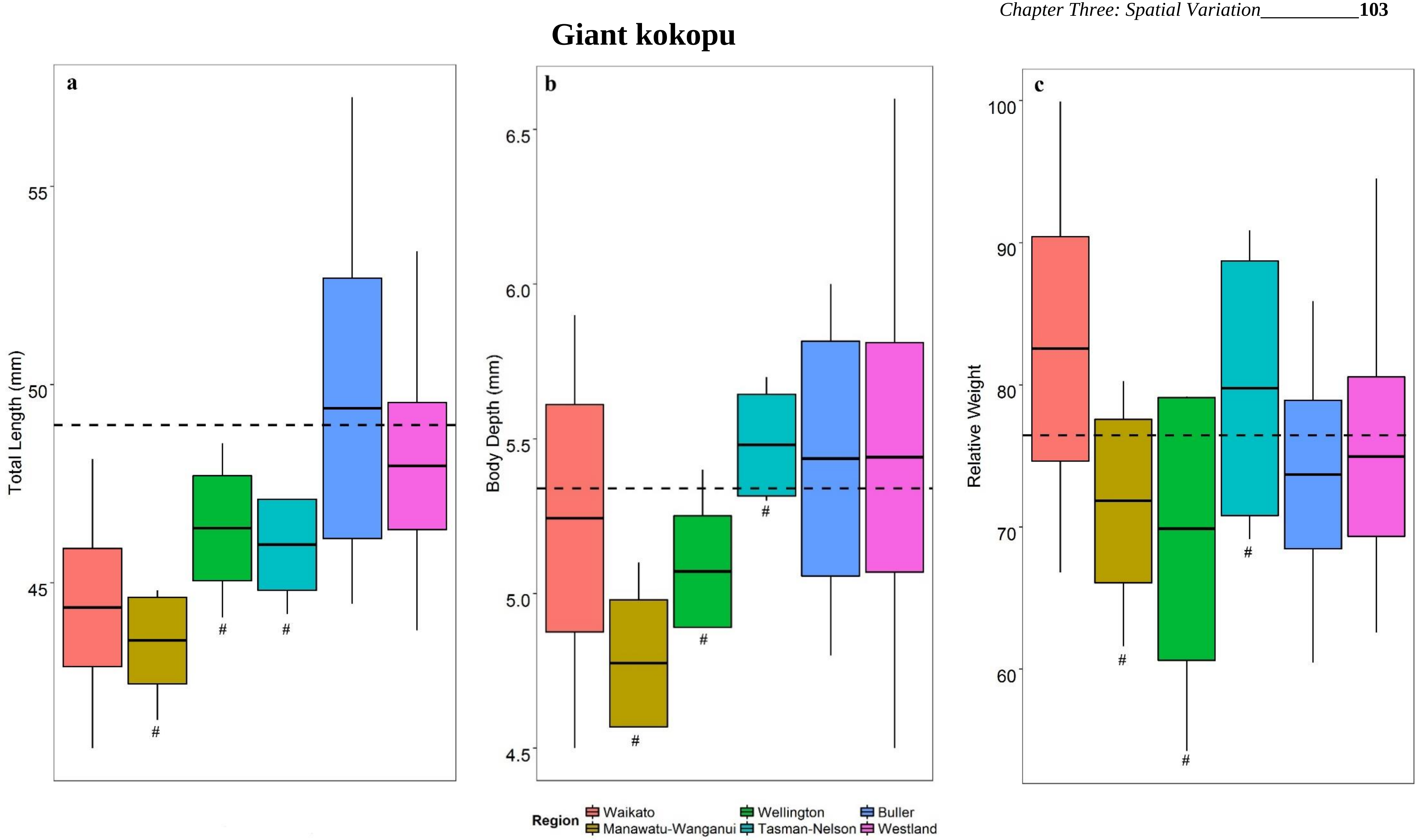


Figure 3.34. Boxplots showing the mean, standard deviation, and minimum/maximum measurements of giant kokopu (a) total length, (b) body depth and (c) condition (relative weight). # = regions excluded from statistical analysis because only one river with more than 5 giant kokopu was sampled. The dotted line represents the monthly mean across all regions.

3.3.2.4 Influence of latitude and whitebait total length

River mouth latitude explained a significant level of variation in total length (across all months combined) of all three common whitebait species (Table 3.11), with length increasing at higher latitudes (Fig. 3.35). For giant kokopu, the same relationship was evident ($F_{1,150}$=127.04, P <0.001), but further analysis was limited because of the low number of giant kokopu numbers in samples (Fig. 3.35).

Inanga, koaro and banded kokopu total lengths also differed between East and West Coasts (Fig. 3.35; Table 3.11). For example, the longest inanga were recorded on the West Coast of the South Island (mean=53mm), followed by the East Coast of the South Island (mean=50mm), followed by the West Coast of the North Island (mean=50mm) and the smallest inanga were recorded on the East Coast of the North Island (mean=48mm) (Fig. 3.36). This pattern was observed for all three species.

Table 3.11. Results of ANCOVA testing the effect of Coast (West Coast vs. East Coast) on the total length of inanga, koaro and banded kokopu with river mouth latitude as a covariate.

Species	**Source of variation**	**SS**	**df**	**F**	**P**
Inanga	**Latitude**	24934.14	1	4314.17	<0.001
	Coast	7084.24	1	1225.73	<0.001
	Residual	46624.01	8067		
Koaro	**Latitude**	2896.57	1	1316.50	<0.001
	Coast	1766.78	1	803.00	<0.001
	Residual	4270.61	1941		
Banded kokopu	**Latitude**	477.93	1	71.97	<0.001
	Coast	1680.68	1	253.09	<0.001
	Residual	10771.26	1622		

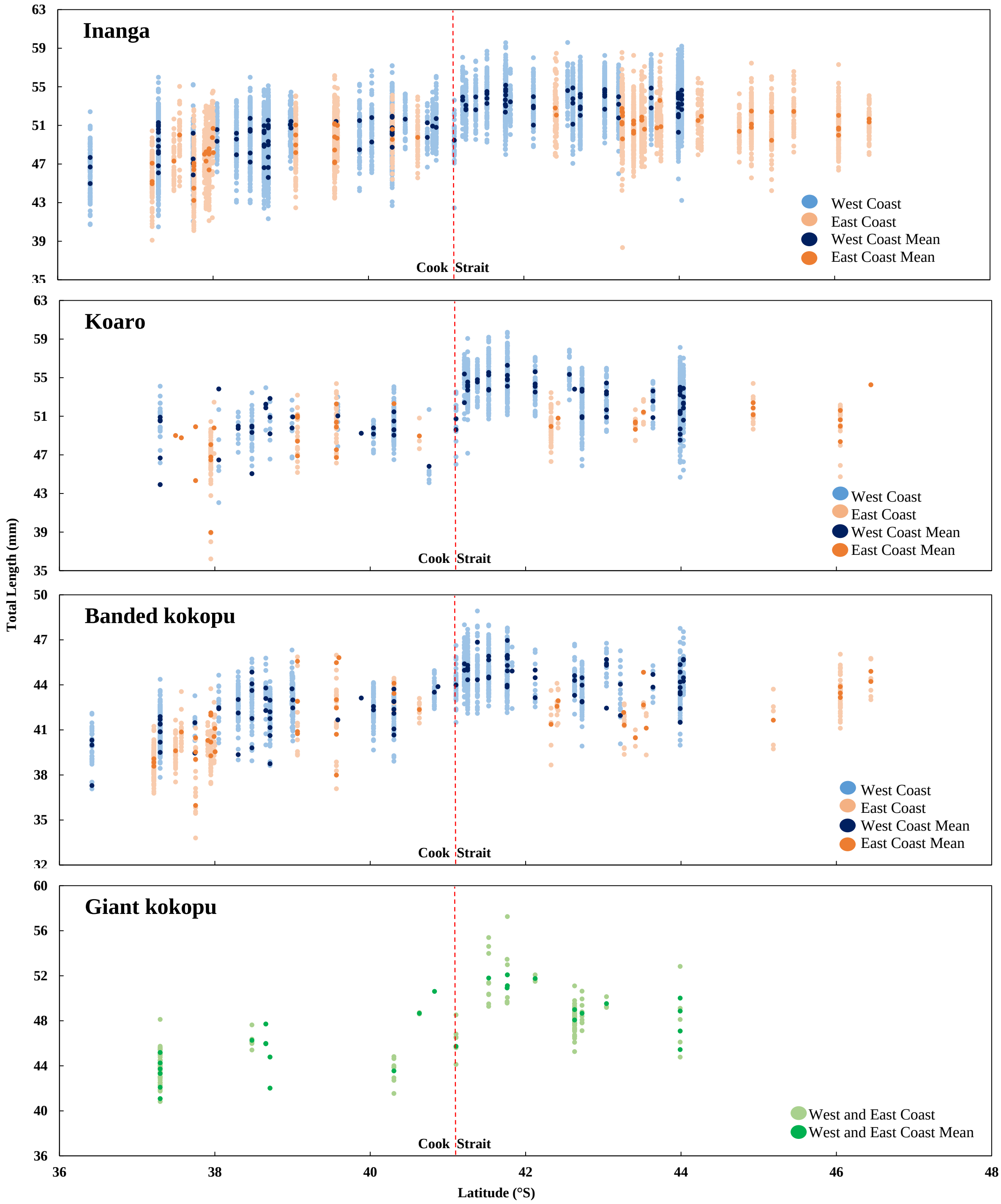


Figure 3.35. Relationship between whitebait length and latitude of inanga, koaro, banded kokopu and giant kokopu. Samples (across all months) from West and East coasts are identified by different colours (Inanga, koaro and banded kokopu: West Coast = orange; East Coast = blue). There were too few giant kokopu from the East Coast of New Zealand to compare coast.

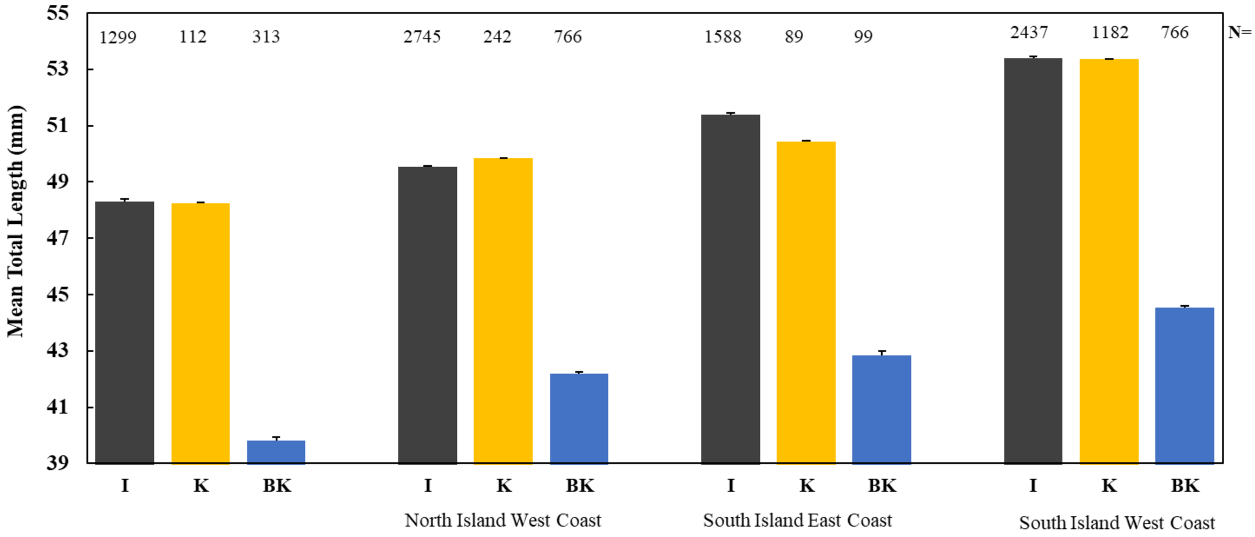


Figure 3.36. Variations in mean inanga length (+SE) between West and East Coasts of the North and South Islands.

3.4 DISCUSSION

3.4.1 Composition

The species composition of whitebait samples throughout New Zealand consisted of high proportions of inanga (88.2%), and low proportions of koaro (5.0%), banded kokopu (6.6%), giant kokopu (0.03%) and shortjaw kokopu (0.01%). This closely aligns with the findings of McDowall (1965), who found 85.2% inanga, 9.7% koaro and 5.1% kokopu species in his samples from across New Zealand.

There were obvious differences in the species composition of whitebait samples from the various regions of New Zealand in September, October and November. These differences varied between months, but Buller always had a different species composition to the other regions.

Buller had higher overall proportions of non-inanga species than other regions. Furthermore, species composition varied considerably among rivers within Buller. Southern Buller rivers (Orowaiti and Buller) had higher proportions of inanga compared to the northern Buller rivers (Oparara, and Karamea).

The Westland current (WEC) forms from water flowing across the Tasman and then moving northeast along the West Coast of the South Island (Ross, 2009) (Fig. 3.2). It is likely that whitebait entering Buller rivers are sourced from Buller and Westland rivers since the WEC flows northwards past all the Buller river mouths. It is possible that Australia may be contributing some inanga and koaro whitebait to Buller and Westland rivers (McDowall et al., 1998; Waters et al., 2000) but whitebait of the other non-inanga species must be coming from New Zealand. Coastal currents along the West Coast could move whitebait northwards, but it is very unlikely that non-inanga whitebait entering West Coast rivers could be sourced from elsewhere in New Zealand. This suggests that they must be retained off the West Coast for the 4-5 months that they are developing as larvae (McDowall & Kelly, 1999).

Generally, regions on the East Coasts of New Zealand had higher proportions of inanga compared to West Coast regions. This pattern was also found by McDowall (1965). Part of the variability among regions and rivers was explained by variations in the proportion of indigenous forest cover. Higher proportions of koaro, banded kokopu and giant kokopu were found when there were higher proportions of forest cover, but other factors also play a part. Similarly, (Rowe et al., 1992) found that rivers in the Bay of Plenty with high proportions of koaro all encompassed extensive areas of native forest in the catchment and contained high densities of adults in its forested tributaries.

East Coast regions, particularly Canterbury (South Island), had very low proportions of koaro, and kokopu species. Records from the freshwater fish database show very limited observations of adult kokopu species in these regions, whereas areas of Fiordland and other parts of Southland have large populations. The Southland current moves water from the lower West Coast and Southland (where large populations of non-inanga adults have been observed) northeast up the East Coast of the South Island. This may suggest that non-inanga species have better retention near their natal rivers. For example, the low proportions of koaro and banded kokopu entering rivers in North Canterbury may have originated from known populations on Banks Peninsula (Fig. 3.22). On the other hand, inanga on the South Island East Coast could be sourced from local rivers, could be swept from Southland by the Southland Current or carried from the West Coast through Cook Strait by the D'Urville current.

Giant kokopu and shortjaw kokopu were found through New Zealand, but comprised a very small proportion of the whitebait samples. They were mainly confined to the West Coast regions of the North and South Islands. These species may be sensitive to land use modification with West Coast regions retaining a lot of forest cover compared to the East Coast (MacLeod & Moller, 2006).

Similarly, there were differences in species composition among rivers within regions. Generally regions on the West Coast of New Zealand showed larger among-river variability than East Coast Regions. This is probably due to the higher proportions of inanga in samples on the East Coast compared to the West Coast (Fig. 3.22). Rivers with large estuaries and harbours potentially have a greater ability to retain whitebait originating in those rivers than rivers that open directly to the sea. For example, in Wellington the Pauahatanui Stream and Hutt River enter into harbours (Porirua and Wellington harbours). Whitebait samples from these rivers had higher proportions of non-inanga species than those from the Waikanae River and Pekapeka Stream which enter directly into the sea. Likewise in Buller, the Oparara and Karamea Rivers have large estuaries (with high proportions of non-inanga species in whitebait samples) while the Buller River enters directly into the sea and samples varied greatly on this river.

The Hapuku River in North Canterbury was the only river throughout the entire study that comprised no inanga in its composition. The Hapuku's steep braided mouth and short, steep catchment potentially allow passage only of the better climbing banded kokopu and koaro species (Appendix 1). Similar to variation in the proportions of koaro (30-94%) in samples on the Waiatoto River, daily fluctuations on rivers in species composition were also observed in previous studies (McDowall & Eldon, 1980). Furthermore, McDowall (1965) found that koaro from cooler glacier fed streams such as the Haast River contained higher proportions of koaro compared to warmer slower, stable, swamp, bush fed streams suggesting temperature may effect migrations.

Smelt, glass eels, juvenile bullies and shrimps found by McDowall (1965) were also found in whitebait samples. Additional species not mentioned by McDowall such as lampreys, and yellow-eyed mullet, were also observed in larger catches from my study. The diadromous lifecycle (movement between freshwater and the sea) of these non-galaxiid species increases their chances of being observed in samples. Smelt at the adult stage were often recognised by whitebaiters as different from galaxiid whitebait, but juvenile bullies were often put aside and thought to be very small whitebait.

Smelt made up the majority of species in samples on some rivers and at certain times of the year. Although, smelt were excluded from samples when identified, the commercial fisherman that provided samples from the Waikato River mouth (Waikato) was unaware he was catching smelt and said restaurants 'preferred the fish he caught to other fisherman further up the river'. Juvenile smelt were largely absent from samples caught upstream, but this shows the importance of smelt for whitebait fishery at the mouth of the Waikato River. There are additional risks associated with the whitebait fishery in the lower Waikato being based around smelt. One of the smelts spawning habitats on sandbars is just as threatened as the riparian spawning habitat of inanga by catchment land-use changes, sedimentation, and controlled flows of the Waikato River. Clearly, if the lower Waikato River smelt populations decrease this will impact heavily on the whitebait fishery at certain times of the whitebaiting season.

3.4.2 Morphology

There was large variation in morphological characteristics among the five whitebait species. Banded kokopu were small in comparison to koaro. Giant kokopu were often intermediate in size, between koaro and banded kokopu, and inanga were the longest whitebait. This is consistent with the results of McDowall and Eldon (1980) who found that the different whitebait species in Westland rivers varied where inanga were longer than koaro and both species were longer than banded kokopu. These sizes ranges of species played in important part in identification of species during laboratory processing. The smallest whitebait were often banded kokopu and the largest koaro with giant kokopu being intermediate in size between the two.

The total length, body depth and relative weight of each whitebait species changed inter- and intra-regionally. West Coast whitebait are longer and heavier than whitebait from other regions in the country such as Waikato and Bay of Plenty. Although a greater overall tonnage may be caught on the West Coast this does not necessarily mean a greater number of fish are caught. For example, a kilogram of inanga whitebait in October in the Bay of Plenty consists of approximately 3185 fish (mean weight: 0.314grams) while in Buller a kilogram of whitebait consists of 2041 fish (mean weight: 0.490grams).

There were variations in the total length of whitebait with river mouth latitude. Whitebait entering rivers at lower latitudes such as those in Bay of Plenty and Waikato (North Island Regions) were smaller than those at higher latitudes such as Buller, Westland and Southland (South Island Regions). These patterns are evident in at least four of the five species. Similar morphological differences among regions and rivers within regions were described by Rowe and Kelly (2009) and McDowall and Eldon (1980) respectively.

The latitudinal change in temperature has been found to affect growth and morphology (body size) of many other species including both ectotherms and endotherms despite some exceptions. Insects (Shelomi, 2012; Eweleit & Reinhold, 2014), birds (Ashton, 2002), and fish (Morita et al., 2010; Rypel, 2013) all appear to follow Bergmann's Rule (Blackburn et al., 1999) despite some variation. It appears that the different water temperatures experienced by whitebait larvae during their planktonic stage that control factors such as growth rate and the timing and rate of tissue development (O'Connor et al., 2007) result in the variable body sizes of whitebait at different latitudes.

In addition to river mouth latitude, coast also affected variability in whitebait length. The largest fish were recorded on the West Coast of the South Island, followed by East Coast South Island, then West Coast North Island and the smallest fish on the East Coast of the North Island. While the sea surface temperatures are similar between the North Island East and West Coasts, and South Island East and West Coasts there are differences in levels of upwelling and productivity (Schiel, 2004). West Coast coastal waters are more nutrient rich than those on the East Coast and this may affect the growth rates of larval whitebait. Fish experiencing the same oceanic conditions (temperature and food supply) may be similar in size. Consistent differences in morphology between regions adds weight to the argument that many whitebait larvae may be retained within regional waters rather than being widely dispersed.

Oceanographic currents on North Island coasts have a greater ability to retain species originating in these regions compared to the South Island. For example, in the North Island the East Cape and Wairarapa eddies are likely to retain whitebait originating in the Bay of Plenty and Hawkes Bay. In contrast, South Island currents on both coasts have the ability disperse fish away from these regions with the Westland current (West Coast) and Southland currents flowing northwards. However, again the clear difference between latitude and coast suggest many developing larvae are retained in these regions.

CHAPTER FOUR: TEMPORAL VARIATION IN THE SPECIES COMPOSITION AND MORPHOLOGY OF THE WHITEBAIT FISHERY

Summary

Variation during 6 months of whitebait migrations

- Species composition and morphology of whitebait samples varied temporally among and within regions.
- Koaro and banded kokopu were present in higher proportions at particular times.
- The timing of species' migrations varied between the North and South Island.
- Giant kokopu and banded kokopu migrated earlier in the North Island than in the South Island.
- Whitebait lengths, body depth, and condition varied throughout the 6 month period.

Variation between years

- Species composition of samples varied significantly in 1 of 5 rivers between years.
- Inanga made up the majority of species in samples during both years.
- Banded kokopu migrated earlier and were more widespread in 2016 than in 2015

Variation over 50 years

- The whitebait catch in 2015 included higher proportions of banded kokopu and lower proportions of koaro and inanga than in 1964.
- Examining the North Island, and East and West Coast of the South Island separately, there were higher proportions of koaro and banded kokopu and lower proportions of inanga in 2015 than previously found.

4.1 Introduction

This chapter examines temporal variability in the species composition and morphology of the New Zealand whitebait fishery across different temporal scales: 6 months, bi-annually in 2015 and 2016, and from 50 years ago. Whitebait species composition and morphology is thought to vary throughout and between seasons. This variation is probably the result of variable conditions, spawned eggs and short-term temporal variability in oceanic conditions affecting larval survival rates. Over longer time periods, any changes in species composition may be the result of the extensive modifications of freshwater ecosystems such as intensification of dairying, agriculture, deforestation, draining of wetlands, damming of rivers, water abstraction, river channelisation, introduction of exotic fish, and commercial and recreational harvesting. Any changes in the species composition and morphology of the whitebait fishery over the last 50 years need to be understood for future discussions about the timing and length of the whitebait open season, spatial management of the fishery and for targeting areas for rehabilitation and conservation management.

4.1.1 Variation during 6 months of whitebait migrations

Past studies have examined species composition throughout the whitebait season, but published results of temporal change only include the months of September, October and November (McDowall & Eldon, 1980). *G. maculatus* were always present, but were observed to make up the highest proportion of catches in September and October. In contrast, *G. brevipinnis* and *G. fasciatus* were not always present but in some rivers, mainly during October (koaro) and November (koaro and banded kokopu), could make up a substantial components (McDowall, 1965; Rowe et al., 1992). An extensive study in Westland and Southland captured the late migration of giant kokopu in November and December (McDowall & Kelly, 1999). Although, these studies were limited to a few rivers in some regions it has been assumed that the observed species migrations and variations in proportions of species between months occur throughout New Zealand.

The morphology of whitebait has been observed to change during the whitebait season with a peak in length in October followed by a decrease in November (McDowall & Eldon, 1980; Rowe & Kelly, 2009). On Westland rivers, McDowall and Eldon (1980) found that although there were day-to-day fluctuations these peaks were consistent between rivers. However, when Rowe and Kelly (2009) examined inanga between one river in both the North Island and South Islands they found that this peak occurred two weeks earlier in the North Island. These studies were not conclusive because they were limited to two regions and only one river in each island was sampled, but it has been assumed that the same trend in length (as well as weights) applies throughout New Zealand with peak lengths being reached earlier in North Island regions than in those in the South Island.

The cues that influence the timing of whitebait spawning (e.g., water temperature, peak spring tides and flood events) (Charteris et al., 2003), as well as air temperatures that influence the rate of egg development (Harzmeyer, 2006), vary between regions. Thus, the timing of spawning (Taylor, 2002)and subsequently of whitebait larvae entering the marine environment differs widely across New Zealand. Taken together with the fact that temperature and productivity of coastal waters differ regionally and temporally (Schiel, 2004), whitebait larvae entering the marine environment at different times will be subjected to variability in temperature, food availability and growth (O'Connor et al., 2007). Therefore, it is expected that the timing of return migrations into freshwater of koaro, banded kokopu and giant kokopu whitebait will vary between regions. Considerable variability in morphology within rivers in regions would suggest greater dispersal and mixing of larvae. Fish entering the marine environment together would be expected to have similar lengths and weights when they return to a river if they have remained together in the same coastal water mass.

4.1.2 Variation between years

There have been no studies that have examined the species composition of the whitebait catch between years. Although, Rowe et al. (1992) sampled over a three year period, results were not compared between years. The only study comparing morphology of whitebait between years was McDowall and Eldon (1980) who found that there was variation in the length of inanga, koaro and banded kokopu over four years in Westland rivers. For example, koaro sampled from the Waiatoto River in 1971 (mean length = 50.5mm) were significantly smaller than those sampled in 1969 (51.8mm) and 1972 (51.5mm).

Given the variability of the timing of spawning and conditions in the marine environments between years it is likely that species composition and morphology will fluctuate between years. However, difference in total length and body depth of whitebait between regions should be somewhat consistent as this variability is likely to be more due to relatively constant differences in oceanic temperatures.

4.1.3 Variation over 50 years

New Zealand's freshwater ecosystems have been modified significantly over the past 50 years (Joy, 2014). These modifications have been associated with declines in many freshwater fish species (Dudgeon et al., 2006) with four of the five species of whitebait now having a 'Threatened' or 'At Risk' conservation rating (Goodman et al., 2013). Despite these dramatic changes it is not known whether the species composition of the whitebait fishery has changed since it was surveyed extensively in 1964 by McDowall (1965).

It is expected that catchment modifications in the past 50 years may have had greater impacts on non-inanga whitebait species and reduced their proportions in current catches. For example, *G. brevipinnis, G. fasciatus* and *G. postvectis* adults typically live in forested headwaters inland from the coast while *G. argenteus* inhabit wetlands and, *G. maculatus* prefers open lowland reaches (McDowall, 1990, 2000). The further upstream a species lives increases the chances of connectivity issues that may be amplified by instream structures such as dams (Jellyman & Harding, 2012). Furthermore, intensification of dairy farming resulting in a loss of a riparian cover, draining of wetlands and reduced water quality increases the loss of suitable habitat for these four species (Joy, 2014; Holmes et al., 2016). Additionally, there has been an increased focus on restoring *G. maculatus* spawning habitat (Taylor, 2002), with projects such as 'Whaka Inaka' in Canterbury which has led to an increase in spawning success and thus perhaps an increase in the proportion of inanga in whitebait catches (Hickford & Schiel, 2013).

In recent years many groups and projects that have targeted the rehabilitation of streams and rivers with the goal of improving water and habitat quality and improving fish passage for aquatic biota. These rehabilitation projects include large-scale planting of riparian margins throughout New Zealand such as 'Million Metres Streams Project', the fencing of streams on farms such as the 'Sustainable Dairying Water Accord' and the development of the 'New Zealand Fish Passage Advisory Group' with a focus on removing barriers to fish migration. While removing fish barriers increases the ability of koaro, banded kokopu, giant kokopu and shortjaw kokopu to migrate upstream to adult habitats, potentially resulting in more koaro and kokopu species in catches (Franklin & Bartels, 2012), the success of riparian planting and habitat improvement in increasing fish biota and production of these species is not known and there is likely to be a lag in seeing positive results (Roni et al., 2008).

The following questions are addressed in this chapter:

1. *Are there small-scale temporal differences in the species composition and morphology of the whitebait catch?*
2. *Are the species composition and morphology of whitebait samples consistent within rivers from year to year?*
3. *Has the species composition of the whitebait fishery changed since it was surveyed by McDowall in the 1960s?*

4.2 Methodology

4.2.1 Variation during 6 months of whitebait migrations

The rivers sampled and field methods used to collect whitebait are discussed in Section 1.2. Species identification and processing are discussed Sections 2.2 and 3.2.

4.2.1.1 Temporal Species Composition among regions

Regions with two or more rivers sampled within each month, with at least 100 fish per sample, and five samples across 3 months, were included in regional temporal composition statistical analyses. These included Waikato, Bay of Plenty, Westland, Canterbury, and Southland (Table 4.1).

Table 4.1. Regions and rivers used in the analyses of temporal variation in whitebait species composition across regions. Yes/No indicates which species were able to be analysed with ANOVA for each river.

Regions	**Rivers**	**Samples**	**Inanga**	**Koaro**	**Banded kokopu**	**Giant kokopu**
Waikato	Waikato River	13	Yes	Yes	Yes	Yes
Waikato	Mokau River	13	Yes	Yes	Yes	Yes
Bay of Plenty	Kaituna River	9	Yes	Yes	Yes	No
Bay of Plenty	Whakatane River	6	Yes	Yes	Yes	No
Canterbury	Saltwater Creek	6	Yes	No	Yes	No
Canterbury	Avon River	8	Yes	Yes	Yes	No
Canterbury	Waimakariri River	8	Yes	Yes	Yes	No
Westland	Hokitika River	6	Yes	Yes	Yes	Yes
Westland	Wanganui River	6	Yes	Yes	Yes	Yes
Westland	Cascade River	6	Yes	Yes	Yes	No
Westland	Waiatoto River	14	Yes	Yes	Yes	Yes
Southland	Waiau River	10	Yes	Yes	Yes	No
Southland	Aparima River	7	Yes	Yes	No	No
Southland	Mataura River	8	Yes	Yes	Yes	No
Southland	Oreti River	7	Yes	Yes	Yes	No

For each species on each river the coefficient of variation was calculated across all samples:

$$\text{Coefficient of variation} = (\text{SD}/\text{Mean})*100$$

In some rivers the proportion of some species was always zero (e.g., no giant kokopu were found in whitebait samples from the three Canterbury rivers; Table 4.1), therefore the coefficient of variation could not be calculated and these rivers was excluded from further analysis (Table 4.1).

One-way ANOVA and SNK post-hoc tests were used to compare the proportional abundances of each whitebait species across regions. This was possible for inanga in all regions and rivers, koaro and banded kokopu in all regions (but including one less river in Canterbury for koaro and in Southland for banded kokopu), and for giant kokopu in Waikato and Westland only (Table 4.1). Shortjaw kokopu were not analysed due to the low number of fish observed. Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. Where Cochran's test for homogeneity of variances remained significant following data transformation the results were interpreted with caution by lowering the significance level to 0.01 (Underwood, 1997).

4.2.1.2 <u>Temporal Species Composition among rivers and regions</u>

Thirty two rivers in 7 regions were targeted for temporal sampling from July to December 2015. Whitebait were caught consistently in only some of these rivers and results are shown for 25 streams where samples were collected across at least 3 months during the July to December sampling period.

Temporal change in species composition within rivers could not be analysed statistically due to the non-replicated nature of the samples.

4.2.1.3 <u>Morphology</u>

4.2.1.3.1 Temporal morphology among regions

In Section 3.3.2 the length, and condition (relative weight) of inanga, koaro, banded and kokopu were analysed spatially and temporally among regions in September, October and November.

Two-way ANOVA and SNK post-hoc tests were used to statistically compare the length and condition (relative weight) of inanga, and koaro across regions where fish were caught across all three months (September, October and November), with month and region as random factors. Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. When Cochran's test for homogeneity of variances remained significant following data transformation, the significance level was lowered to 0.01 (Underwood, 1997). One-way ANOVA was used for banded kokopu as only one region had them in September, October and November and giant kokopu could not be compared.

4.2.1.3.2 Temporal morphology within rivers

Rivers included in comparison of species composition in section 4.2.1.2 were used to compare species morphology across months. This included rivers with at least five samples across 3 months with at least 10 inanga and 5 koaro, banded kokopu and giant kokopu.

One-way ANOVAs were used to compare the lengths of each whitebait species in rivers where species were present. Data were log-transformed when appropriate to improve normality and remove variance heterogeneity. Where Cochran's test for homogeneity of variances remained significant following data transformation, the results were interpreted with caution by lowering the significance level to 0.01 (Underwood, 1997).

4.2.2 Variation between years

Eight rivers from five regions sampled in 2015 were re-sampled in 2016. These included the Waikato River (Waikato), Kaituna River (Bay of Plenty), Waimakariri River (Canterbury), Avon River (Canterbury), Wanganui River (Westland), Waiatoto River (Westland), Aparima River (Southland) and Waiau River (Southland). Five of these eight rivers provided enough samples to allow a comparison between years.

The same methodology as used in 2015 was used for 2016 sampling (Section 1.2) and laboratory processing (Sections 2.2 and 3.2).

4.2.2.1 <u>Statistical analysis</u>

A Permutational Multivariate Analysis of Variance (PERMANOVA) was used to compare whitebait species composition in rivers between 2015 and 2016 samples. To compare these, paired samples were chosen within each month; paired samples with fewer than 100 fish were excluded from analysis. The PERMANOVA was run on PRIMER V6 using a Bray-Curtis dissimilarity matrix on untransformed data. Each PERMANOVA had one fixed factor (river).

4.2.3 Variation over 50 years

4.2.3.1 Comparison of whitebait species composition from 1964 and 2015

Species compositions from 2015 were compared to data collected in by McDowall (1965) in 1964.

For consistency, when comparing species composition data from the McDowall (1965) study with 2015 data, the original (1965) filtering criteria were used:

1. Kokopu species (banded, giant and shortjaw) were grouped together.
2. Only whitebait samples with ≥ 9 fish were included in the analysis.
3. Only samples caught during August to November (North Island) and September to November (South Island) were used.
4. The only regions included in the analysis were Waikato, Taranaki, Hawkes Bay, Wellington, Nelson-Marlborough, Canterbury, Otago, and Buller-Westland.
5. Waikato River samples were excluded from the data set.

The raw data from this study could not be obtained so no statistical analysis could be completed.

4.2.3.2 Comparison of whitebait species composition from 1981 to 1983 and 2015/2016 in Bay of Plenty Rivers

Species compositions from 2015/2016 samples were compared to results from Rowe et al. (1992). To be consistent with the Rowe et al. (1992) study, only species compositions from samples with ≥ 100 fish and rivers with ≥ 2 samples were included in the analysis. Data collected on the Kaituna River in 2015 and 2016 were combined for this analysis.

The raw data from the 1983 study could not be obtained so no statistical analysis could be completed.

4.2.3.3 Comparison of morphology data from 1969 to 1972 and 2015 to 2016

Total length data for inanga from the Waiatoto River (Westland) in 2015/2016 were compared with historical data of length to caudal fork from 1969 - 1972 from McDowall and Eldon (1980).

Figures from McDowall and Eldon (1980) were digitised using the TechDig V2.0d software to allow graphical comparison with 2015/2016 data. The raw data from this study could not be obtained so no statistical analysis could be completed.

4.3 RESULTS

4.3.1 Variation during 6 months of whitebait migrations

4.3.1.1 Temporal Species Composition among regions

The species composition of whitebait samples was found to vary between regions in September, October and November (Fig. 3.7 to 3.9). There were high proportions of inanga in all months in all regions. While there was little variation in some East Coast regions between months (Hawkes Bay, Canterbury and Otago) there was considerable variation in West Coast Regions. In October, there were higher proportions of koaro and banded kokopu in samples from Waikato, Manawatu-Wanganui, Buller and Westland compared to September and November. For example, mean species composition of September samples from Waikato were comprised of 92% inanga, 1% koaro and 7% banded kokopu, but in October samples consisted of 82% inanga, 2% koaro and 15% banded kokopu. In November this changed again to 99% inanga (Fig. 3.7 to 3.9).

The proportion of inanga in whitebait samples was very consistent in most rivers (Table 4.2). For example, the coefficient of variation (CV) for the proportion of inanga in 8 samples in the Avon River (Canterbury) was 0.19, but was 33.5 from 14 samples from the Waiatoto River (Westland). The proportion of non-inanga whitebait in samples was generally much more variable than inanga proportions. For example, the proportion of inanga in 13 samples from the Mokau River (Waikato) was relatively consistent (CV =15.4) compared to the highly variable proportions of koaro (CV = 208.6), banded kokopu (234.4) and giant kokopu (360.56).

Individual rivers were used as replicates within regions to compare coefficients of variation between regions. There were significant differences between regions for inanga, but not for koaro, banded kokopu or giant kokopu (Fig. 4.1; Table 4.3). However, SNK post hoc tests could not find these differences between regions.

Table 4.2. Coefficient of variation from rivers sampled temporally and used in the analyses of species composition across regions (to show temporal variation across rivers in species composition).

Regions	**Rivers**	**Samples**	**Inanga**	**Koaro**	**Banded kokopu**	**Giant kokopu**
Waikato	Waikato River	13	13.7	191.0	174.7	196.8
Waikato	Mokau River	13	15.4	208.6	234.4	360.6
Bay of Plenty	Kaituna River	9	6.6	199.7	223.9	NA
Bay of Plenty	Whakatane River	6	7.7	91.6	217.3	NA
Canterbury	Saltwater Creek	6	0.5	NA	165.5	NA
Canterbury	Avon River	8	0.2	185.3	256.8	NA
Canterbury	Waimakariri River	8	1.0	107.3	141.8	NA
Westland	Hokitika River	6	24.9	133.1	184.7	245.0
Westland	Wanganui River	6	4.7	128.7	126.6	245.0
Westland	Cascade River	6	6.9	85.5	83.7	NA
Westland	Waiatoto River	14	33.5	125.2	126.8	237.7
Southland	Waiau River	10	13.6	170.6	224.9	NA
Southland	Aparima River	7	0.8	202.0	NA	NA
Southland	Mataura River	8	15.3	139.9	185.3	NA
Southland	Oreti River	7	1.1	264.6	264.6	NA

NA= coefficient variation calculation not possible due to species not being present in river.

Table 4.3. Summary of ANOVA testing for differences among regions in the coefficient variation of proportions of inanga, koaro, banded kokopu and giant kokopu in whitebait samples.

Species	**Source of variation**	**SS**	**df**	**F**	**P**
Inanga	Region	1.97	4	3.80	<0.05
	Residual	1.30	10		
Koaro	Region	15666.3	4	1.85	0.20
	Residual	19006.6	9		
Banded kokopu	Region	19980.2	4	2.5727	0.11
	Residual	17474.3	9		
Giant kokopu	Region	1567.3	1	0.35	0.60
	Residual	13440.9	3		

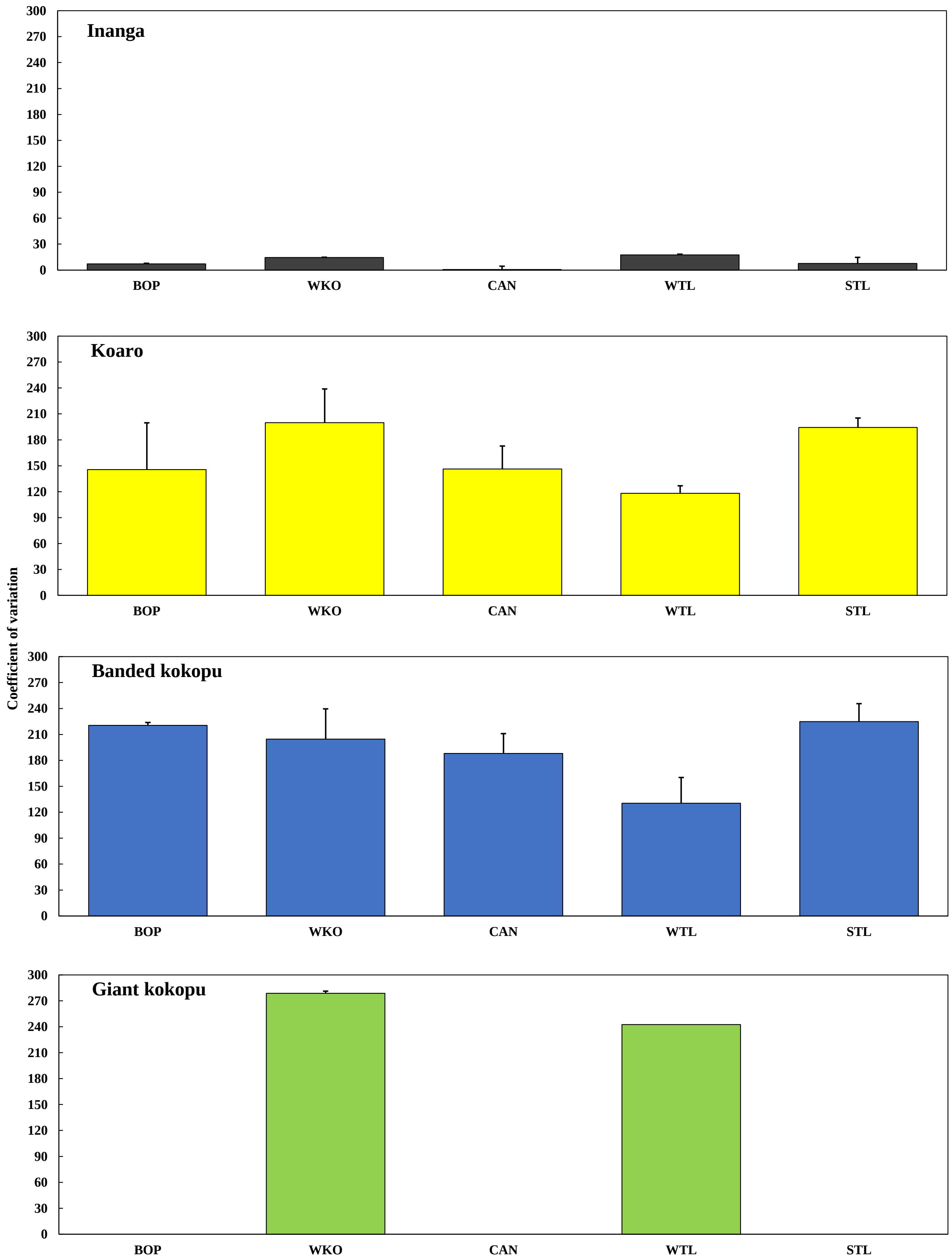


Figure 4.1. Mean coefficient of variation (±SE) for the proportion of inanga (black), koaro (yellow), banded kokopu (blue) and giant kokopu (green) in whitebait samples from five regions. Abbreviations for regions: Bay of Plenty (BOP), Waikato (WKO), Canterbury (CAN), Westland (WTL) and Southland (SLT).

4.3.1.2 Temporal Species Composition among rivers and regions

The species composition of whitebait samples collected for spatial analysis varied greatly between July and December (Fig. 3.12 to 3.18). In July and August inanga made up the highest proportion of species in samples throughout New Zealand (Fig. 3.12 and 3.13). In September koaro became more common in samples from rivers in Westland, Buller, Tasman-Nelson and Bay of Plenty rivers, and the proportion of banded kokopu in samples, particularly in rivers from Buller and Waikato increased (Fig. 3.14). In October, there were relatively high proportions of banded kokopu in Buller and Tasman-Nelson river samples and low proportions of giant kokopu in samples from rivers on the West Coast of the North Island (Fig. 3.15). In November, koaro and banded kokopu were far less common in samples from the West Coast (Fig 3.16). By December, the few samples obtained consisted mainly of inanga with low proportions of giant kokopu in samples from some rivers on the West Coast (Fig. 3.16 & 3.17).

Individual rivers that were sampled more frequently throughout the 6 month period for temporal analysis also showed considerable variation in species composition. In North Island West Coast rivers early and late samples consisted mainly of inanga, but samples in September and October contained as high as 26% banded kokopu on the Waikato, Awakino and Mokau Rivers (Waikato) and as high as 19% koaro on the Rangitikei River (Manawatu-Wanganui; Fig. 4.2). Giant kokopu were recorded in samples from on all four rivers but in low proportions (0.3-2.8%). A single shortjaw was found in a sample from the Rangitikei River in November.

Whitebait samples from North Island East Coast Rivers consisted of mainly inanga (Fig. 4.3). Koaro were present in samples from the Whakatane River mainly in September, and low proportions of banded kokopu were observed in samples in October (1-14%; Whakatane River) and November (5-20%; Kaituna River). Koaro and banded kokopu were also found in samples from the Tutaekuri River (Hawkes Bay) from the end of September to the middle of November but in very low proportions (1-5%).

There was considerable variability in the species composition of whitebait samples from rivers in the northern part of the South Island (Fig. 4.4). The Takaka and Wainui Rivers (Tasman-Nelson) had very high proportions of banded kokopu and koaro compared to the Wairau River diversion (Marlborough) which was dominated by inanga throughout. Three whitebait samples from the Takaka River consisted of 34-70% koaro and three samples from the Wainui River consisted of 34-67% banded kokopu.

On the West Coast of the South Island, samples from rivers in Buller comprised high proportions of koaro and banded kokopu throughout the sampling period (Fig. 4.5). A sample from the Mokihinui River in October contained 90% banded kokopu and from the Buller River two samples from October and November consisted of 47% koaro. Giant kokopu were observed in low proportions (1-16%) in all three rivers while a single shortjaw kokopu was only observed from a sample on the Buller River.

All Westland rivers had koaro and banded kokopu in at least one of their samples, but there was considerable variation in proportions (Fig. 4.6). Wanganui and Cascade Rivers had lower proportions of these species and Waimea Creek, Hokitika River and Waiatoto River had samples with higher proportions. Waimea Creek was of interest with all three samples caught at the end of November and December consisting of 19-47% giant kokopu.

On the East Coast of the South Island (Canterbury) all 21 samples collected from the 3 rivers consisted of at least 97% inanga (Fig. 4.7). Very low proportions of banded kokopu and koaro were recorded in samples from the Avon and Waimakariri Rivers and banded kokopu only in Saltwater Creek from the late October to late December.

On the Southern Coast of the South Island (Southland) inanga made up the majority of whitebait samples (Fig. 4.8). However, koaro and banded kokopu were also observed at some time during the sampling period on all 6 rivers. In October and November the Waiau and Mataura Rivers were found to have higher proportions of koaro than the other rivers in Southland ($\leq$ 25% Mataura River; $\leq$ 33% Waiau River).

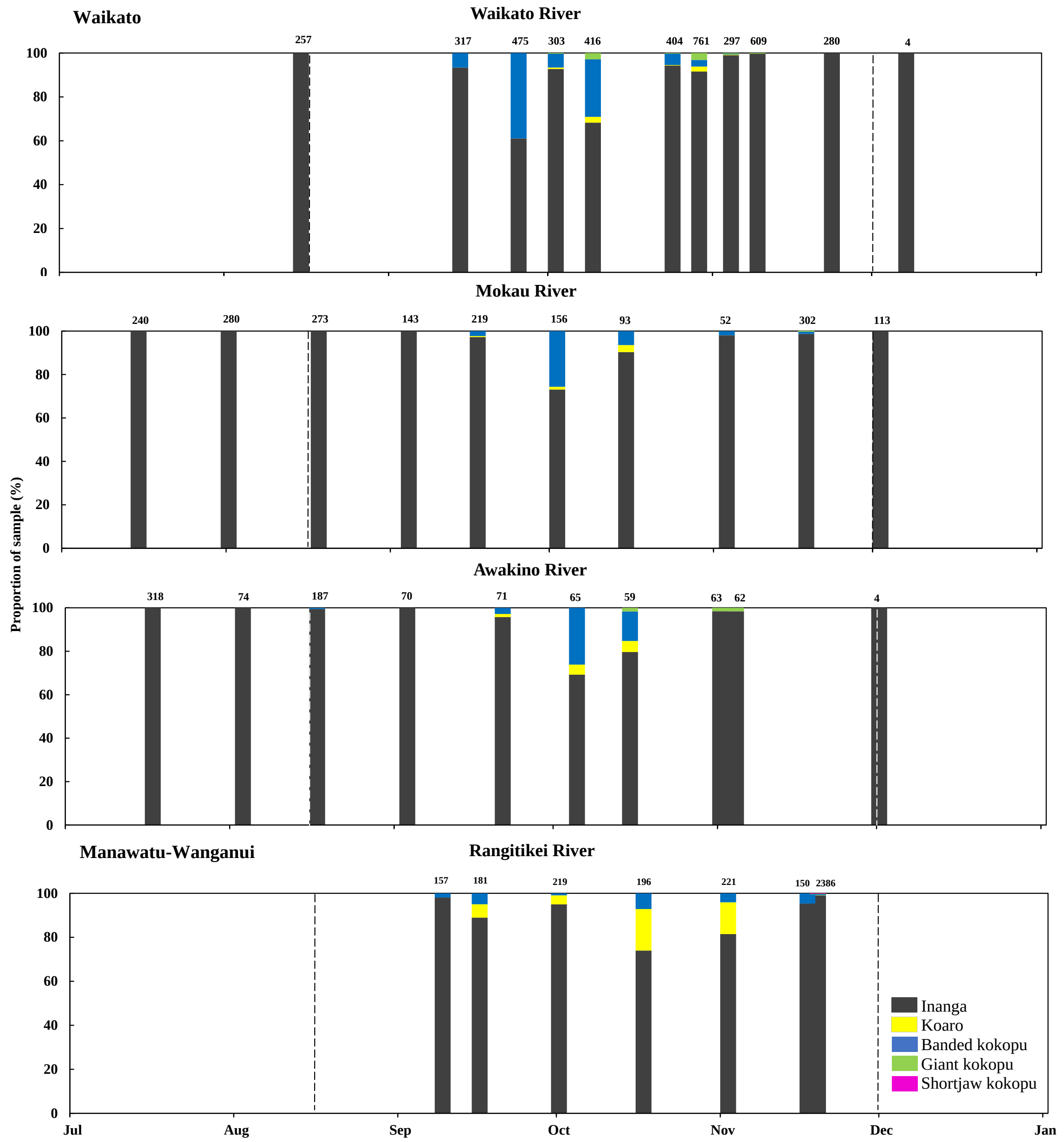


Figure 4.2. Species composition from July to December of whitebait samples from 4 rivers in Waikato and Manawatu-Wanganui (West Coast, North Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

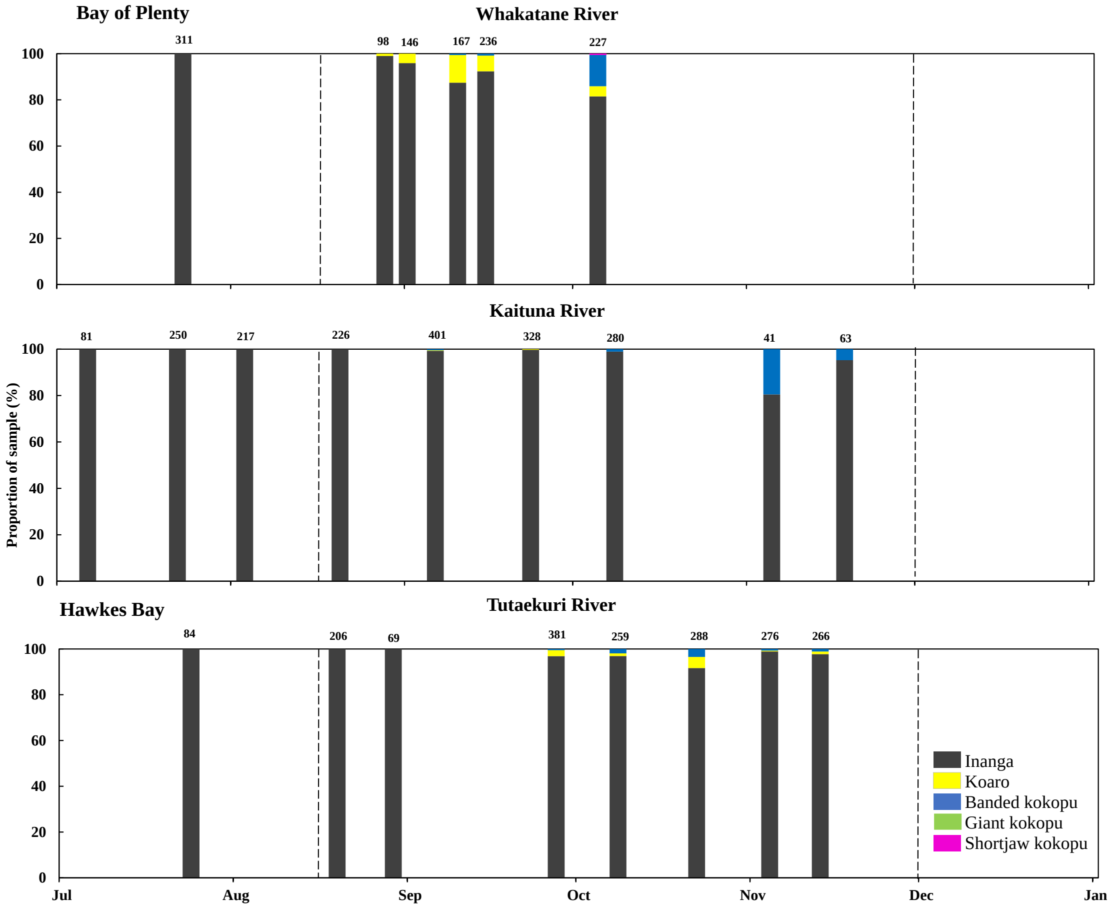


Figure 4.3. Species composition from July to December of whitebait samples from 3 rivers in Bay of Plenty and Hawkes Bay (East Coast, North Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

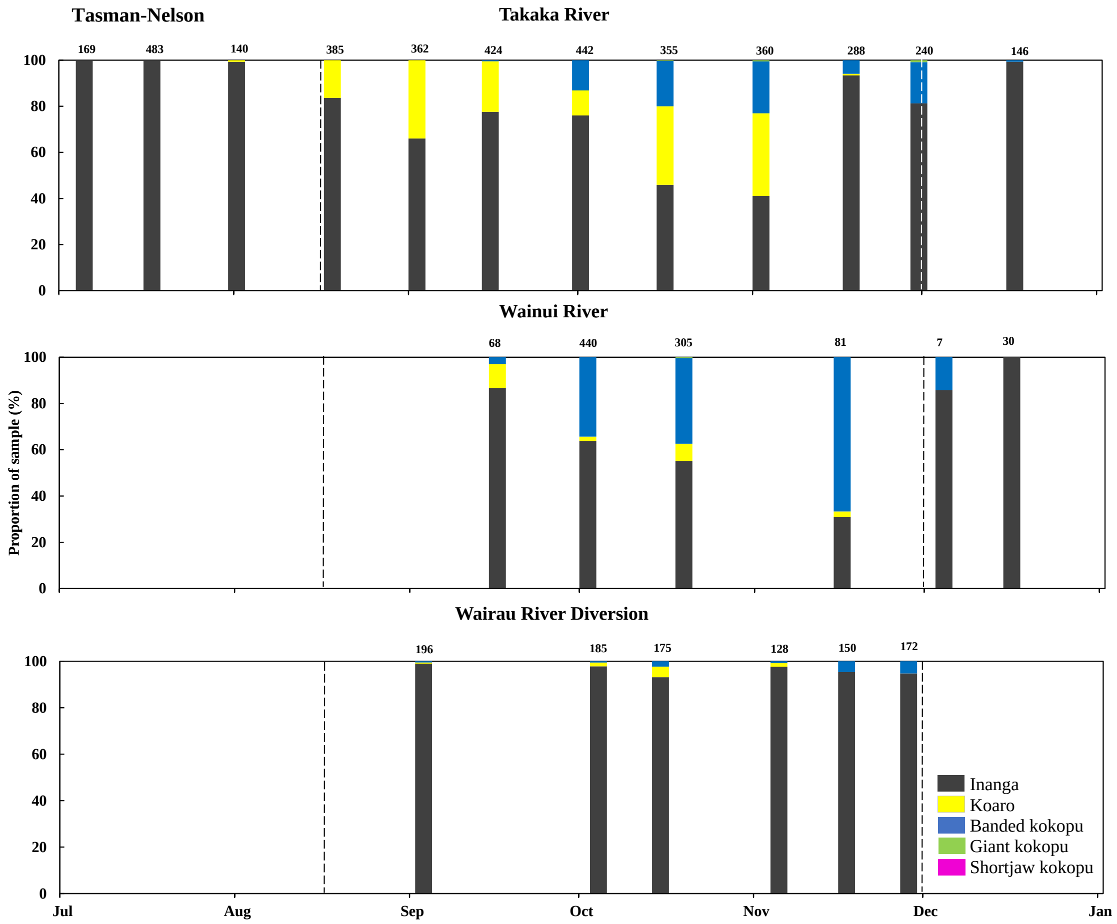


Figure 4.4. Species composition from July to December of samples from 3 rivers in Tasman-Nelson and Marlborough (North Coast, South Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

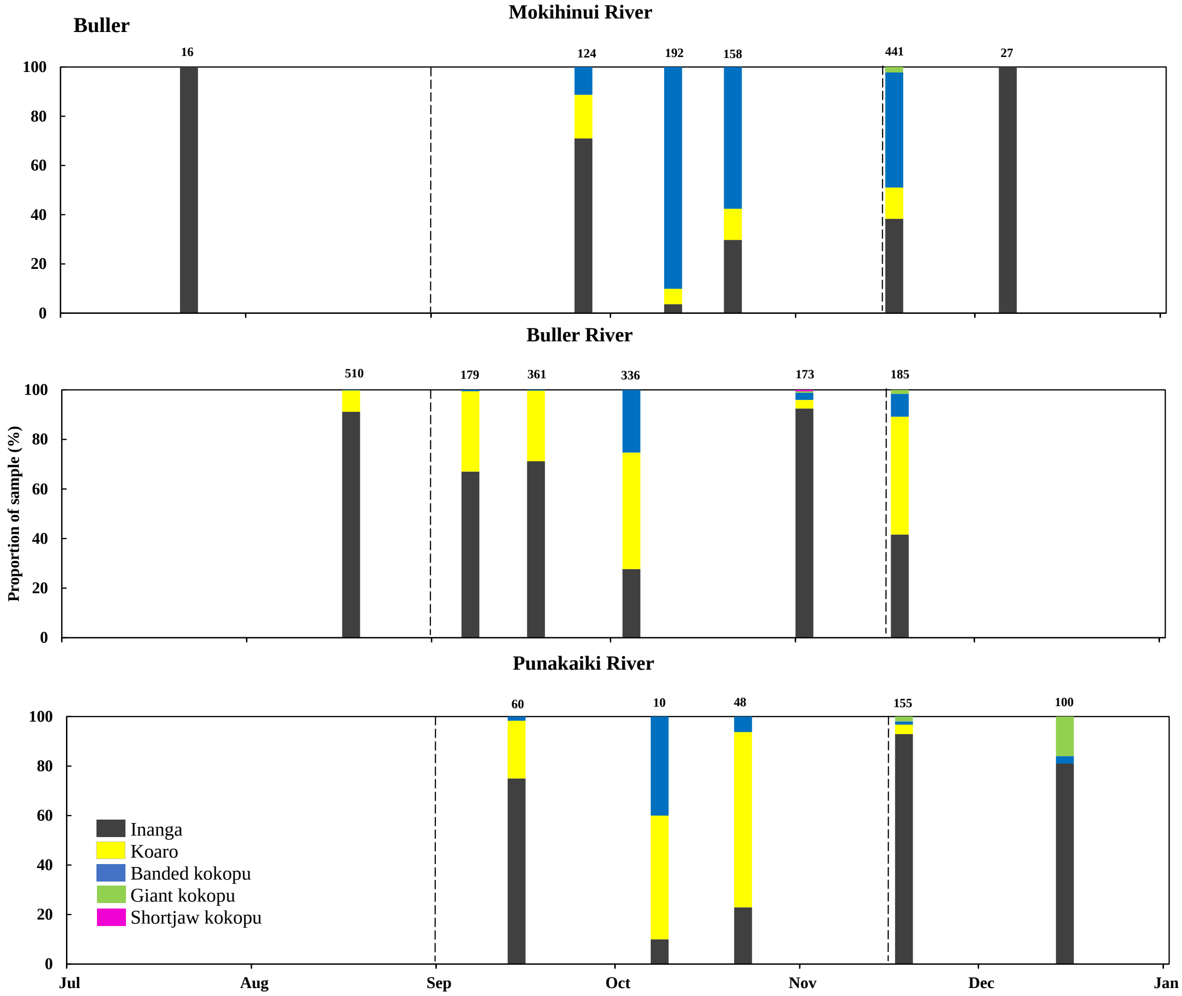


Figure 4.5. Species composition from July to December of samples from 3 rivers in Buller (West Coast, South Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

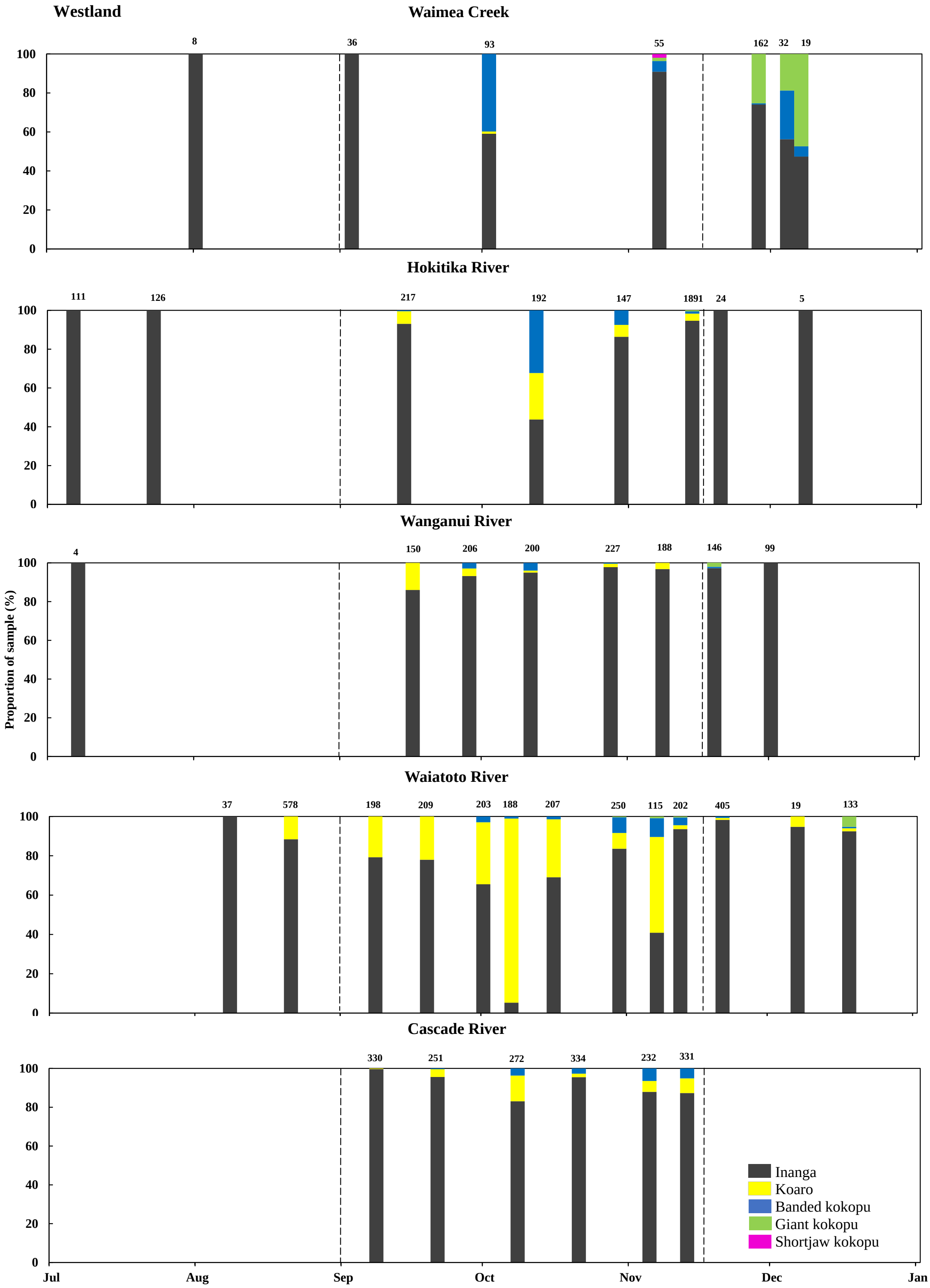


Figure 4.6. Species composition from July to December of whitebait samples from 5 rivers in Westland (West Coast, South Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

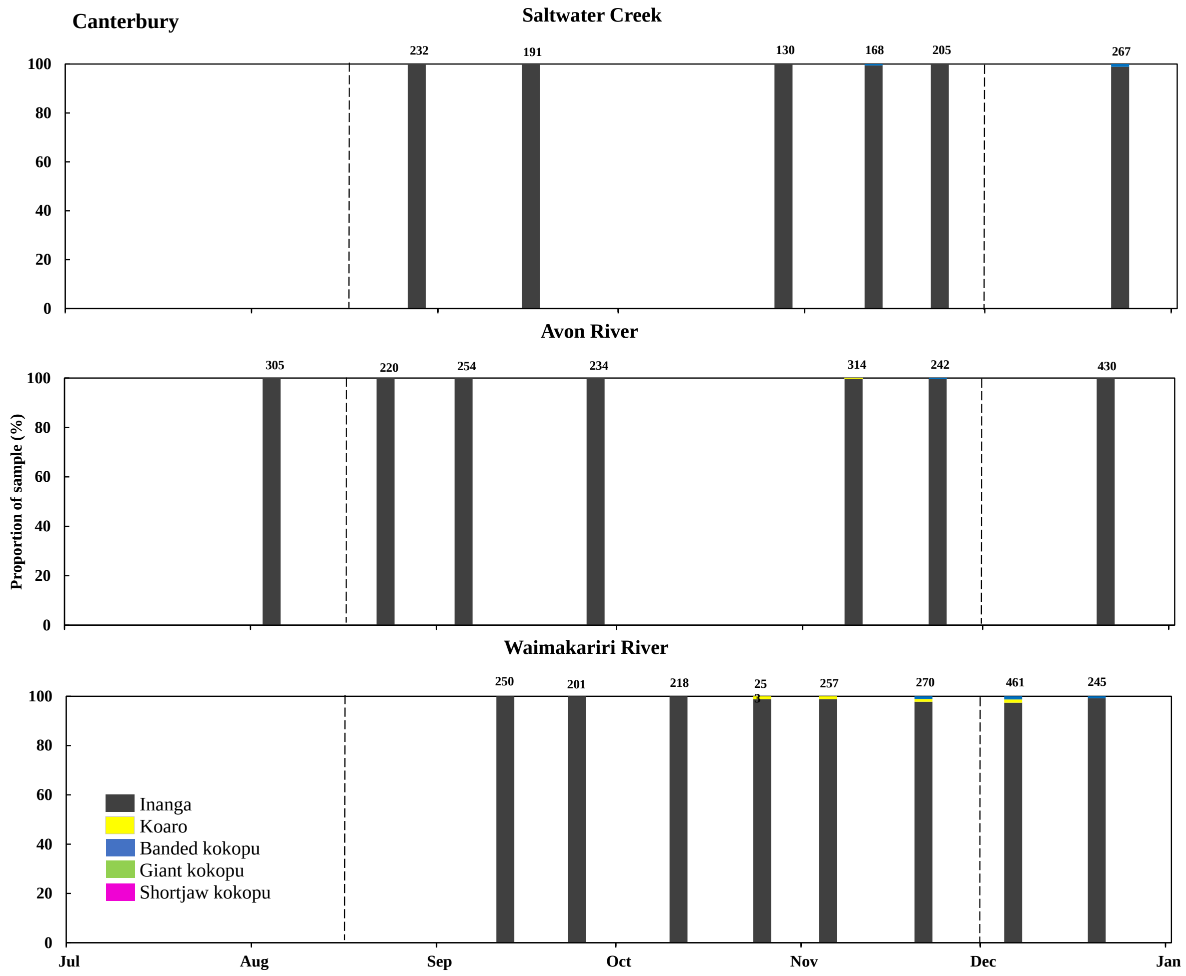


Figure 4.7. Species composition from July to December of whitebait samples from 3 rivers in Canterbury (South Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

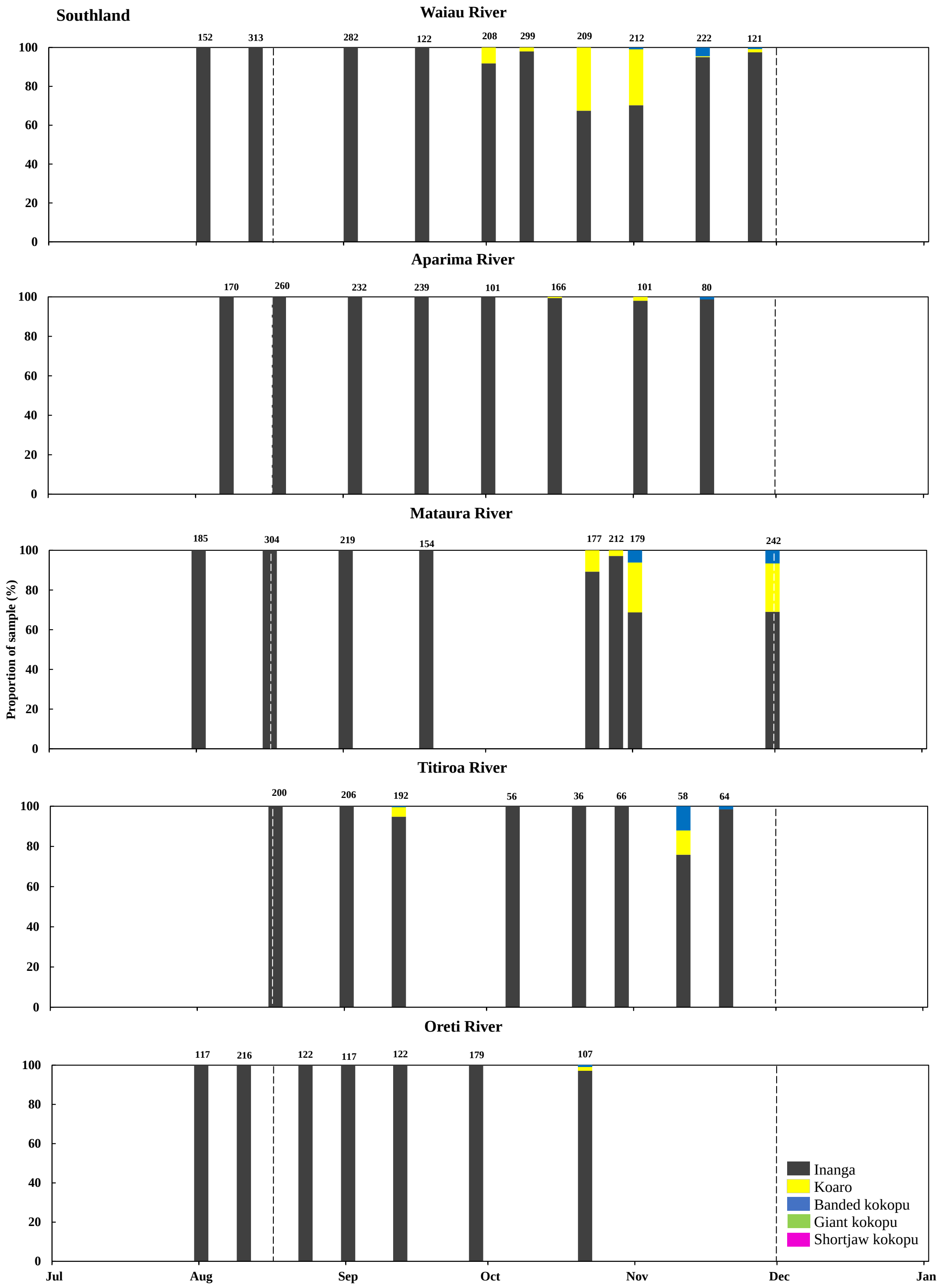


Figure 4.8. Species composition from July to December of whitebait samples from 5 rivers in Southland (South Coast, South Island). The current open whitebait season sits within the dotted lines. Samples sizes are shown above data points.

4.3.1.2.1 Timing of species migration between regions

The species composition of whitebait samples changed throughout the whitebait season. The proportions of inanga in samples were consistently high from July through to December. The proportions of koaro, banded kokopu, giant kokopu and shortjaw kokopu in samples varied and thus the peak migration times were easier to identify.

Peak migrations of banded kokopu were earlier on the west coast of the North Island than in much of the South Island. In the North Island, banded kokopu peak migrations in the Waikato (west coast) were from mid-September to mid-October, in Bay of Plenty and Hawkes Bay (east coast) peak migrations were from late October to mid-November (Fig.4.9). In the South Island, peak migrations of banded kokopu in Tasman-Nelson, Buller, and Westland rivers (west coast) were mainly from mid-October to mid- November (Fig. 4.10). In Canterbury and Southland (east coast), banded kokopu were far less common, but peak migrations were between mid-November and early December (Fig. 4.11).

The timing of koaro migrations was very variable across New Zealand. Koaro migrated from early August until early December in rivers on the west coast of South Island (Fig. 4.10). In South Island east coast rivers, koaro migrations occurred from late September to early December (Fig. 4.11). On North Island rivers, koaro migrations runs were generally shorter in duration from September to November (Fig 4.9).

Migrations of giant kokopu were earlier in North Island rivers than in South Island rivers. In the North Island, giant kokopu were found to run from the last few days in September on the Waikato River and from the middle of October on the Awakino River until mid-November (Fig. 4.9). In Tasman-Nelson, Buller and Westland rivers they were found to migrate from mid-October through until mid-December (Fig. 4.10).

The few shortjaw that were present in whitebait samples from the North and South Islands were observed earlier (October) in one sample from the Bay of Plenty in the North Island compared to those recorded in rivers on the West Coast of the South Island (November; Fig. 3.18). In the North Island, shortjaw were found in a sample on 5th October on the Whakatane River (Bay of Plenty) and 19th November on the Rangitikei River (Manawatu-Wanganui). In the South Island on the Buller and Mokihinui Rivers (Buller) shortjaw were found on 2nd and 9th November, and in a whitebait sample from Waimea Creek (Westland) on 9th November.

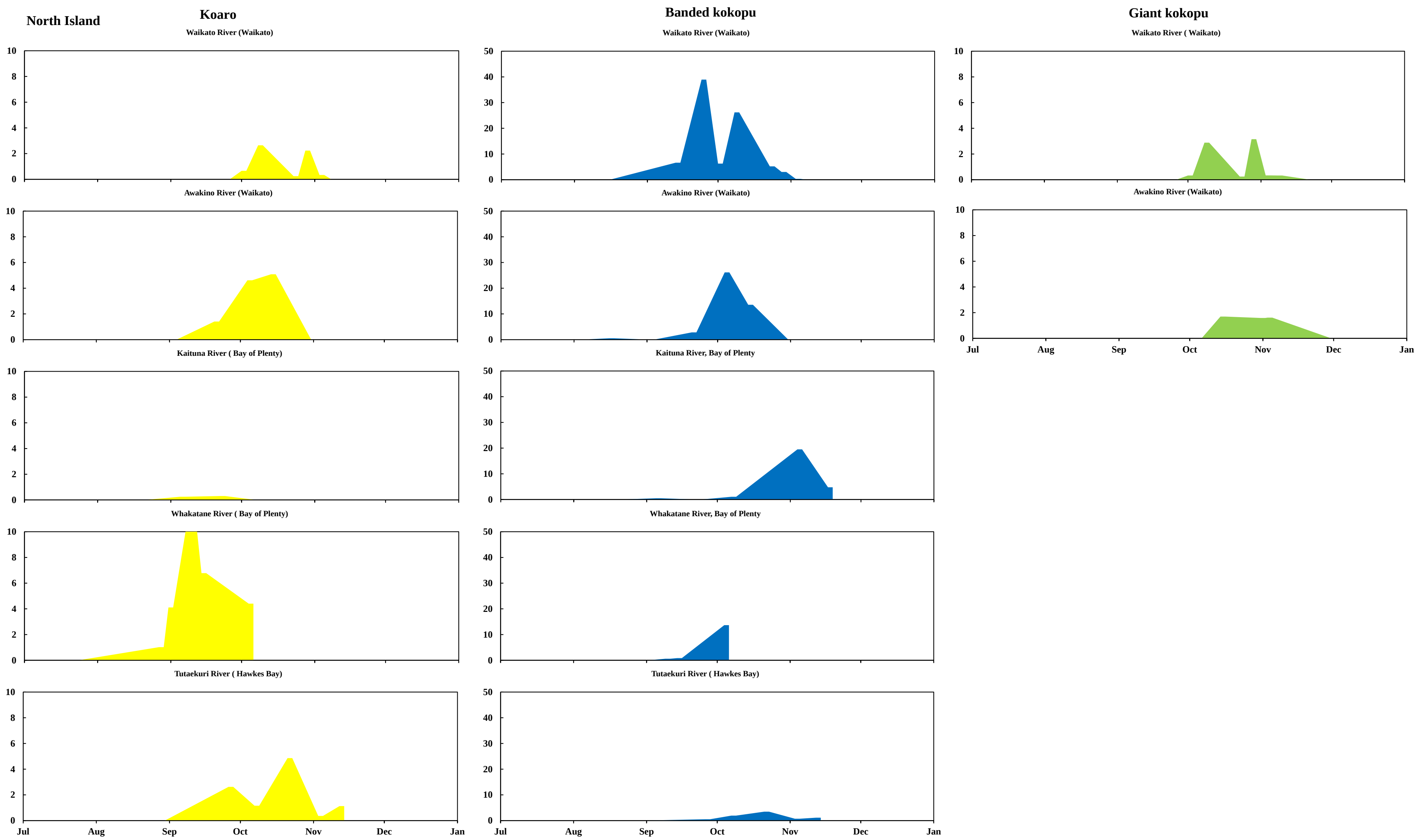


Figure 4.9. The timing of species migration of koaro (yellow), banded kokopu (blue) and giant kokopu (green) from July to December from 5 rivers in Waikato, Bay of Plenty and Hawkes Bay (North Island, West and East Coast).

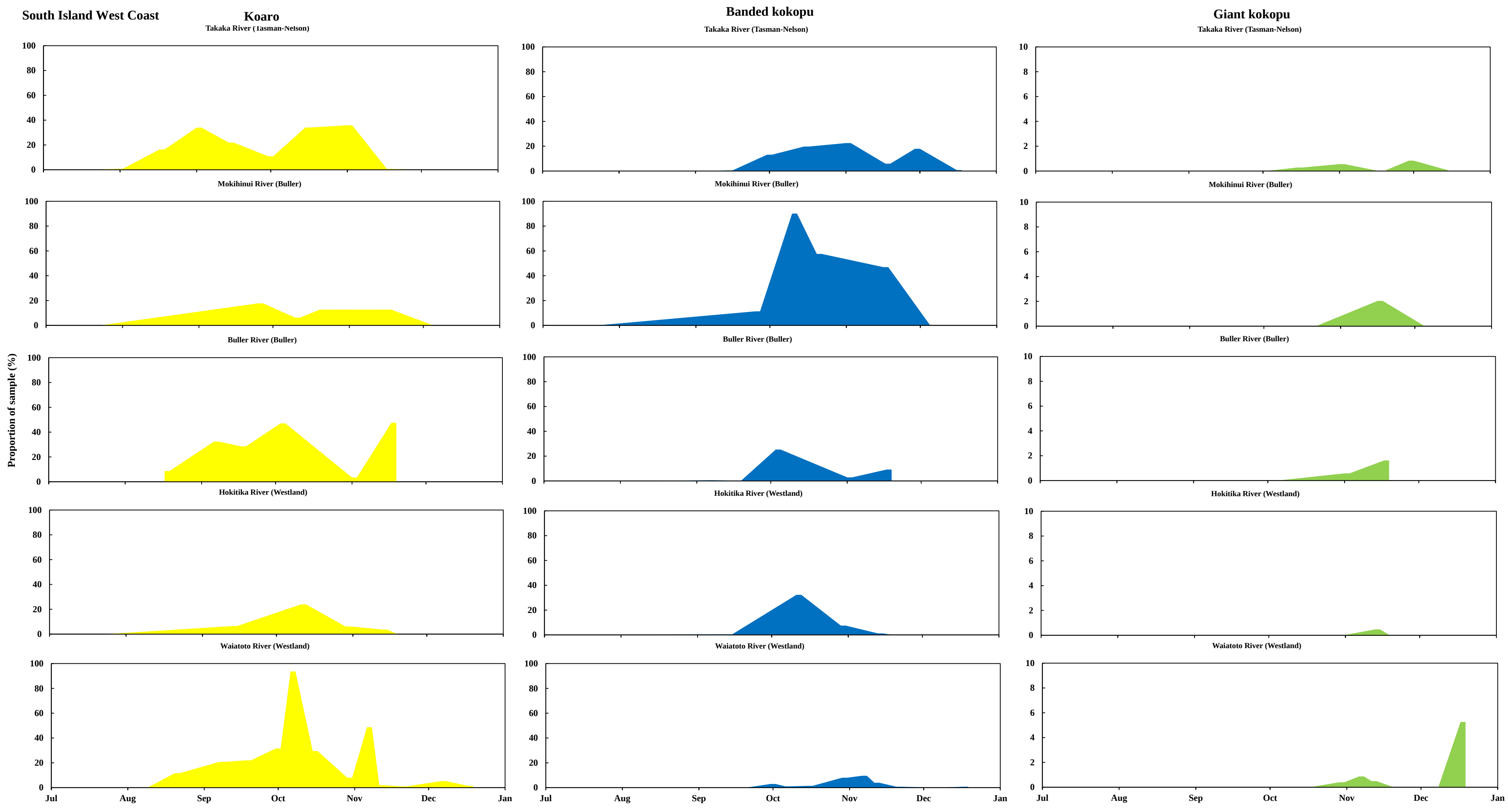


Figure 4.10. The timing of species migration of koaro (yellow), banded kokopu (blue) and giant kokopu (green) from July to December from 5 rivers in Tasman-Nelson, Buller and Westland (South Island, West Coast).

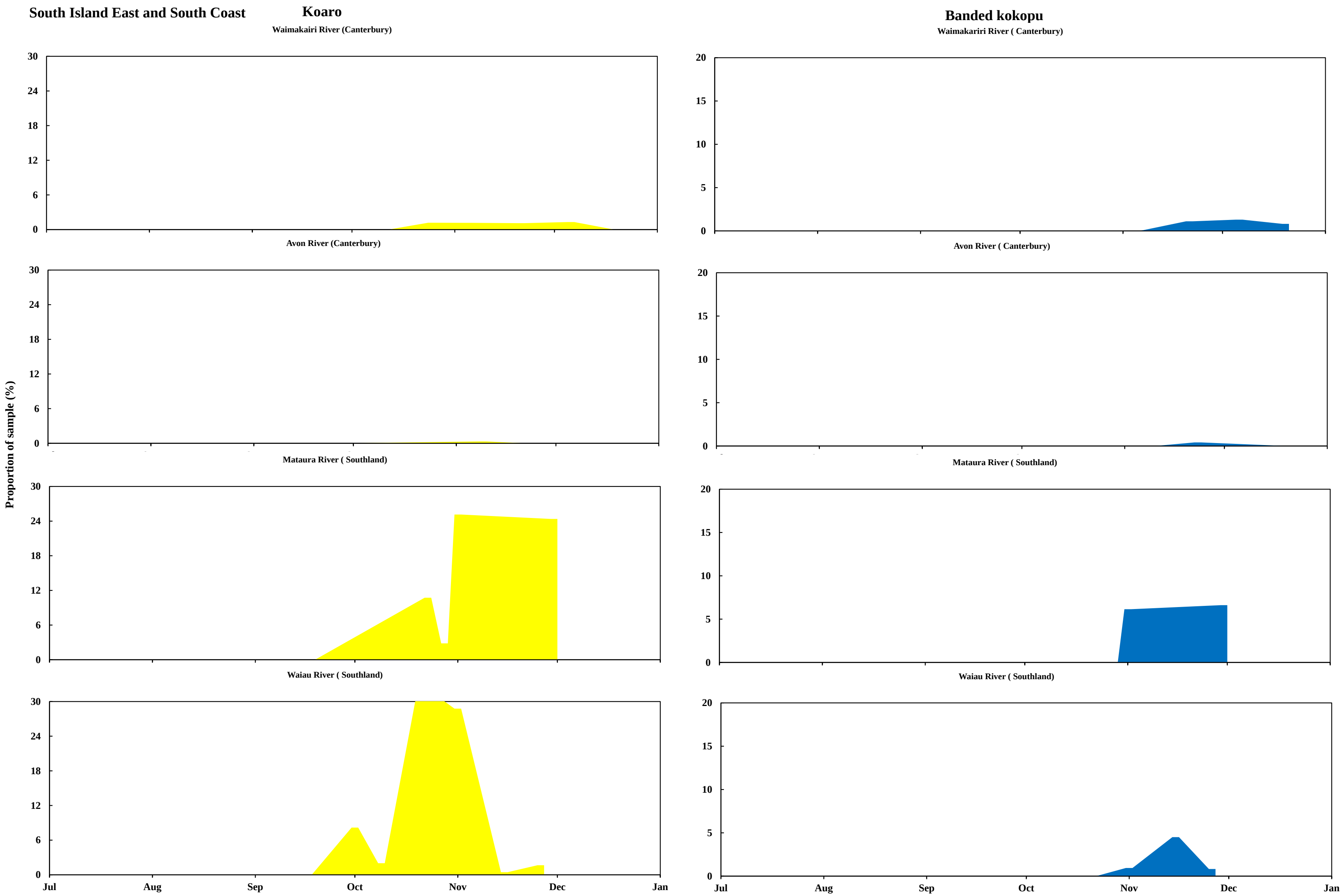


Figure 4.11. The timing of species migration of koaro (yellow), banded kokopu (blue) and giant kokopu (green) from July to December from 4 rivers in Canterbury and Southland (South Island, East and South Coasts).

4.3.1.3 Morphology

4.3.1.3.1 Temporal morphology among regions

The total length and condition of inanga, koaro, and banded kokopu in whitebait samples differed significantly among regions and across months, but the differences were not uniform (Fig. 3.25 to 3.33; Table 4.4, 4.5 & 4.6).

The mean total length for inanga in September across all regions was 52.4mm, 51.6mm in October and 52.4mm in November. For koaro, mean total lengths were 54.2mm in September, 53.5 in October and 52.4 in November.

There was a significant decrease in the mean total length of inanga in many, but not all, regions over the three month period (Table 4.4). In Waikato, inanga total lengths decreased significantly across the three months (4.9mm decrease overall), but in Canterbury (0.3mm) and Buller (0.2mm) there were no significant decreases (Fig. 3.24). The condition of inanga whitebait peaked in October and decreased significantly thereafter across most regions (Table 4.4). For example, in Buller the mean condition (relative weight) was 102.8 in September, it increased to 111.4 in October then decreased again to 98.2 in November.

For koaro, the mean total length decreased significantly across the three months in the two regions where they were caught in all three months (Buller and Westland; Table 4.5). In Westland, mean total length was 53.8mm in September, 52.9 in October and 50.7 in November. The condition (relative weight) of koaro decreased from September to November (Table 4.5). In Buller this difference was not significant in September and October but was in November and is Westland between all three months.

Buller was the only region where banded kokopu were caught in sufficient numbers to be able --to analysed across months (September to November). SNK post hoc tests showed that mean length in September and October were the same, but banded kokopu whitebait were smaller in November (Table 4.6). As with inanga, the condition of banded kokopu whitebait peaked in October and was significantly lower in September and November (Table 4.6).

Table 4.4. ANOVA testing the effect of month and region on the total length and condition (relative weight) of inanga in samples from September to November in Waikato, Manawatu, Hawkes Bay, Tasman-Nelson, Canterbury, Buller, Westland, and Southland rivers.

Characteristic	**Source of variation**	**SS**	**df**	**F**	**P**
Total length (mm)	**Month**	3129	2	456	<0.001
	Region	20971	7	873	<0.001
	Month/Region	1880	14	39	<0.001
	Residual	24390	7104		
Condition (Relative Weight)	**Month**	25716	2	94.2	<0.001
	Region	105720	7	110.7	<0.001
	Month/Region	51783	14	27.1	<0.001
	Residual	969212	7104		

Table 4.5. ANOVA testing the effect of month and region on the total length and condition (relative weight) of koaro in samples from September to November in Buller and Westland rivers.

Characteristic	**Source of variation**	**SS**	**df**	**F**	**P**
Total length (mm)	**Month**	288.91	2	51.33	<0.001
	Region	1325.52	1	471.03	<0.001
	Month/Region	665.87	2	118.31	<0.001
	Residual	3157.43	1122		
Condition (Relative Weight)	**Month**	1812.54	2	6.10	<0.01
	Region	36777.02	1	247.72	<0.001
	Month/Region	9150.82	2	30.82	<0.001
	Residual	166574.11	1122		

Table 4.6. ANOVA testing the effect of month and region on the total length and condition (relative weight) of banded kokopu in samples from September to November in Buller.

Characteristic	Source of variation	SS	df	F	P
Total length (mm)	**Month**	95.6	2	41.5	<0.001
	Residual	479.5	416		
Condition (Relative Weight)	**Month**	0.34	2	81.98	<0.001
	Residual	0.86	416		

4.3.1.3.2 Temporal morphology within rivers

There were significant changes in the total length of inanga from all 25 rivers throughout the country between July and December. Similarly, the total length of koaro changed in 14 of 16 rivers, and banded kokopu in 11 of 16 rivers (Fig. 4.12 to 4.18, Appendix 5, Table A5.1). Giant kokopu were only observed in temporal samples from two rivers and mean total length did not differ between these samples.

<u>Inanga total length</u>

Mean total length of inanga was observed to fluctuate between samples in all rivers, but the overarching pattern was an initial increase in mean total length followed by a decrease in later samples. However, the timing of this peak varied in rivers from different parts of the country with a latitudinal gradient appearing to effect this timing.

In North Island rivers, there was a decrease in inanga length from September in Bay of Plenty (Fig. 4.13), Waikato, Hawkes Bay and the Rangitikei River (Manawatu-Wanganui; Fig. 4.12). However, in South Island rivers the timing of this decrease in inanga length was in November for rivers in Tasman-Nelson, Buller, and Westland (Fig. 4.14, 4.15 and 4.16). The exceptions were Southland rivers where the decrease occurred slightly earlier (mid-October) and in Canterbury rivers from the start of September (Fig 4.17 and 4.18). Generally, rivers at lower latitudes had earlier decreases in mean total length than rivers at higher latitudes.

On some of the South Island Rivers where inanga were caught in July and August, such as Takaka River (Tasman-Nelson), Mokihinui River (Buller) and Hokitika and Waiatoto Rivers

(Westland), fish in earlier samples were initially smaller before reaching a peak in total length in late September or early October.

Koaro total length

There was a lot of variability in koaro total lengths between samples over the 6 months of sampling. In contrast to the distinct decrease in total length observed for inanga and banded kokopu, this pattern was not observed for koaro on most rivers apart from those in Westland (Fig. 4.16). On the Rangitikei River (Manawatu-Wanganui; Fig. 4.12), Takaka and Wainui rivers (Tasman-Nelson; Fig. 4.14) and Mokihinui, Buller and Punakaiki Rivers (Buller; Fig. 4.15) fish decreased in total length in October followed by a subsequent increase. Again, the timing of this varied on rivers in different parts of the country.

Of interest was a significant increase in koaro total length on the Whakatane River (Bay of Plenty). The mean lengths of koaro in whitebait samples in the first two weeks of September differed by 9.1mm (1 September: 39.0mm, 10 September: 48.1mm) (Fig. 4.13). This represents a 23% increase in mean total length over an eight day period.

Banded kokopu total length

Banded kokopu were observed in whitebait samples from rivers over a much shorter time frame than inanga or koaro. Banded kokopu mean total lengths fluctuated between samples, but patterns were observed on some rivers with a peak and then decrease in length. As with inanga, the timing of this peak varied in different rivers around the country.

In North Island rivers there was a distinct decreases in total mean length at the end of October on the Waikato river (Waikato) and start of November on the Rangitikei River (Manawatu-Hawkes Bay; Fig 4.12). In South island, the Takaka and Wainui Rivers (Tasman-Nelson; Fig. 4.14) showed steep declines in mean total length from mid-October and the Waiatoto and Cascade Rivers (Westland) showed a similar decline in early November (Fig. 4.16). In contrast, the Mokihinui and Buller Rivers (Buller) were found to have different patterns with stable or increasing mean total lengths (Fig. 4.15).

Giant kokopu total length

Giant kokopu were only found on the Waikato River (Waikato) and Waimea Creek (Westland) in great enough numbers to analyse temporal changes between samples. In both cases there was no significant change in the mean total length of giant kokopu in the whitebait samples.

Total length between species

In most rivers and at most times, inanga whitebait had the greatest mean total length, followed by koaro and giant kokopu, with banded kokopu being the smallest (Figs 4.12 to 4.18). However, in later samples from Buller (Mokihinui, Buller and Punakaiki Rivers; Fig. 4.15) and Southland (Mataura, Waiau and Titiroa Rivers; 4.18), when inanga total lengths had begun to decline significantly, the largest whitebait in samples were koaro.

Of interest was that for many rivers many of the whitebait species showed parallel temporal changes in total length. For example, in the Waikato (inanga and banded kokopu; Fig. 4.12), Rangitikei (inanga, koaro and banded kokopu; Fig. 4.12), Takaka (inanga, koaro and banded kokopu; Fig. 4.14), Buller (inanga and koaro; Fig. 4.15), Hokitika (inanga, koaro and banded kokopu; Fig. 4.16), Waiatoto (inanga and koaro; Fig. 4.16) and Cascade (inanga, koaro and banded kokopu; Fig. 4.16) Rivers at least two of the whitebait species showed several synchronous increases or decreases in mean total length.

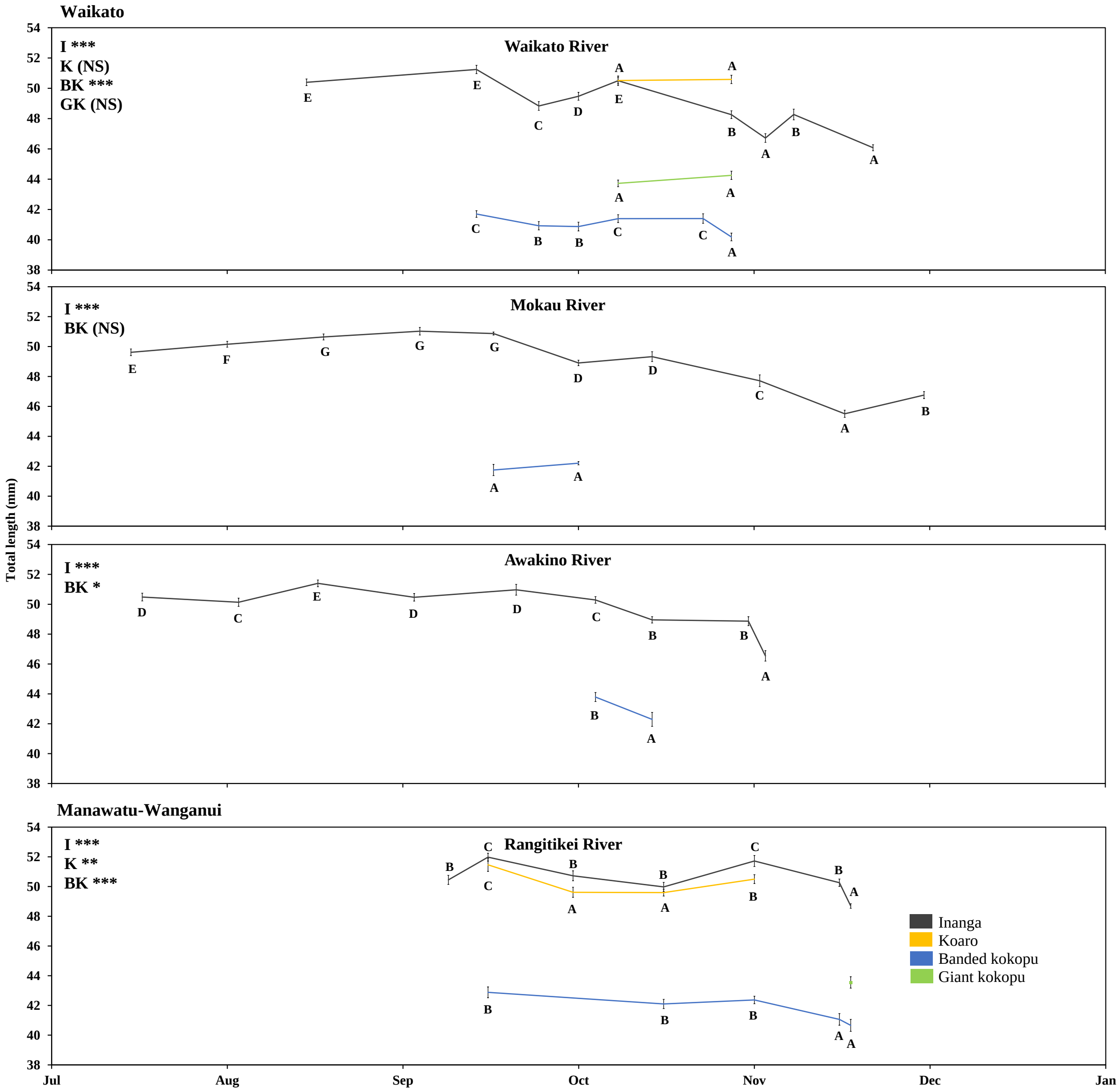


Figure 4.12. Mean total length (±SE) of whitebait species in samples collected between July and December from four rivers in Waikato and Manawatu-Wanganui (West Coast, North Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-G).

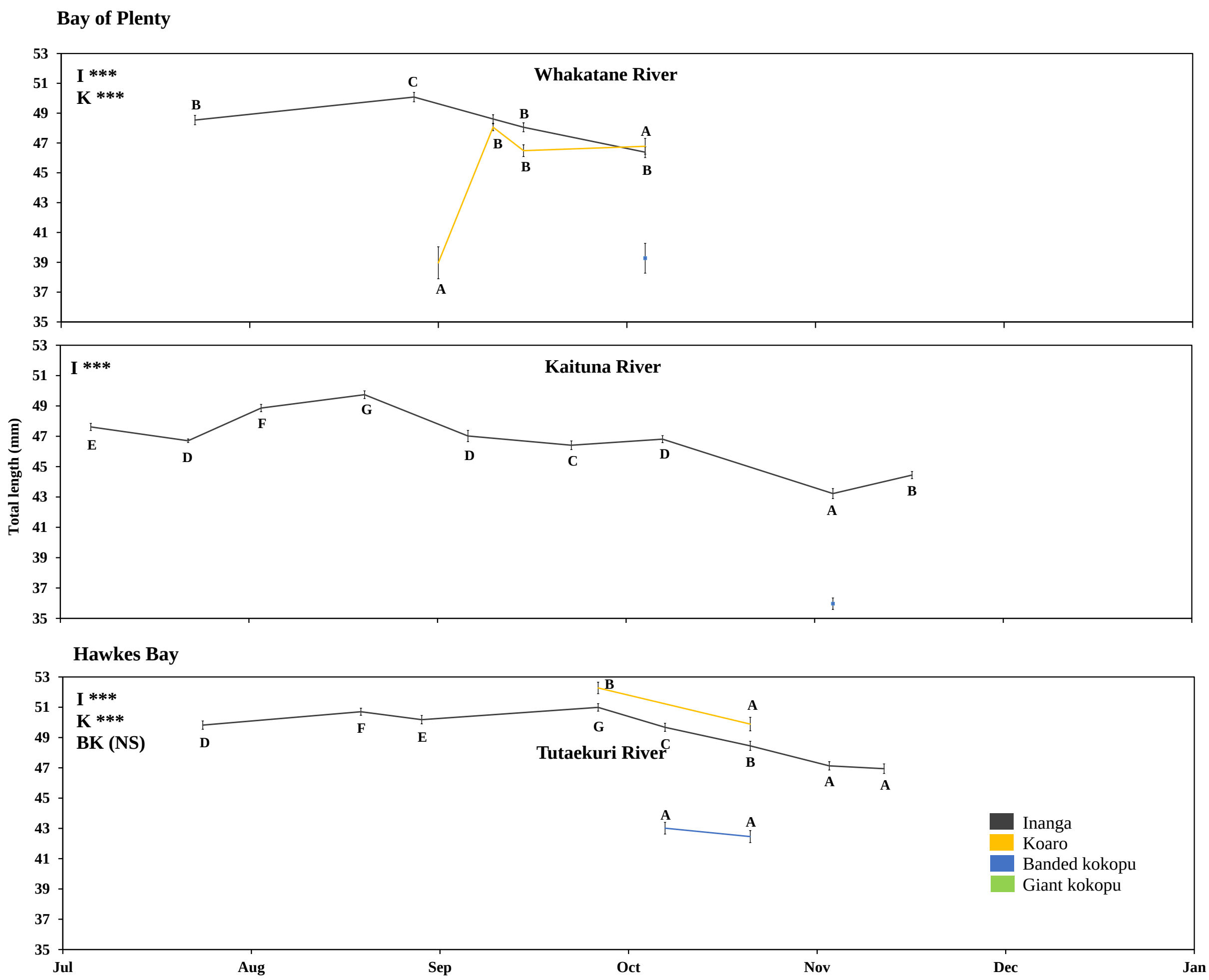


Figure 4.13. Mean total length (±SE) of whitebait species in samples collected between July and December from 3 rivers in Bay of Plenty and Hawkes Bay (East Coast, North Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-G).

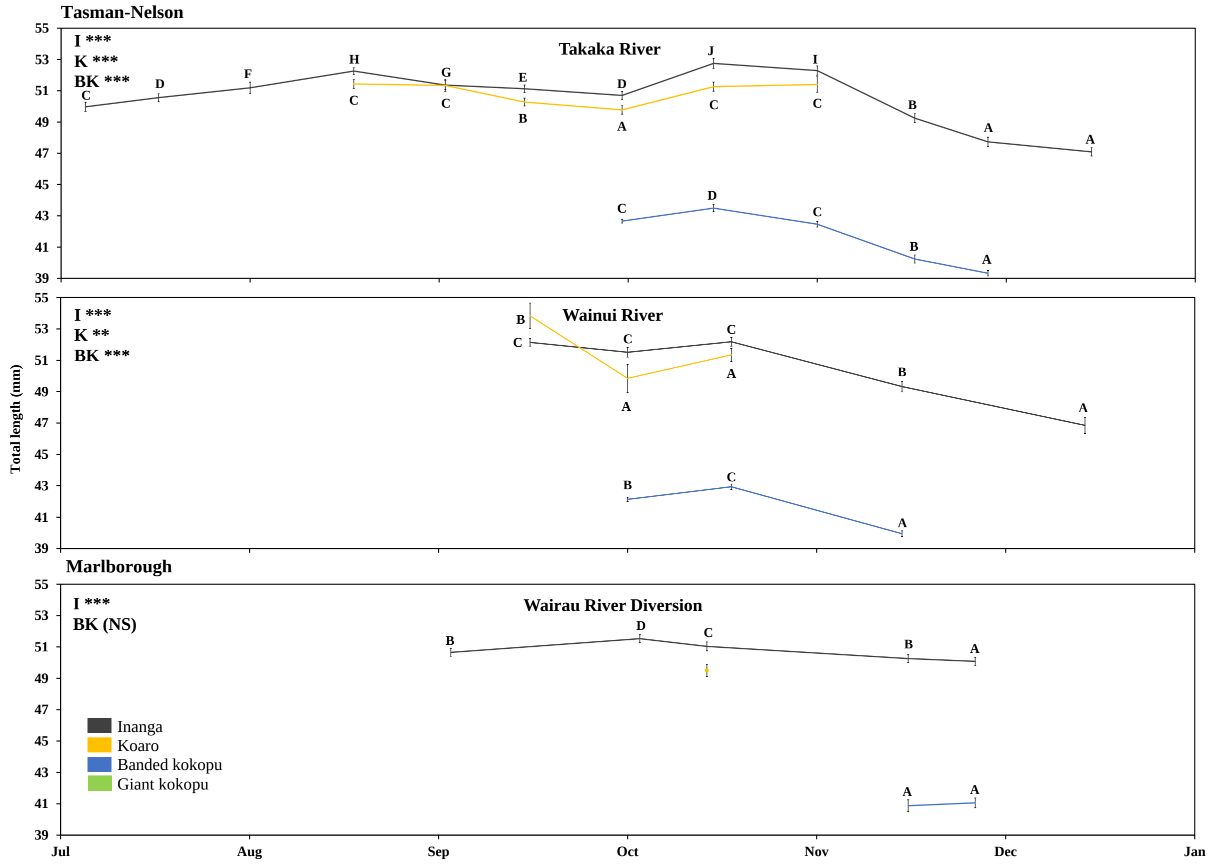


Figure 4.14. Mean total length (±SE) of whitebait species in samples collected between July and December from 3 rivers in Tasman-Nelson and Marlborough (North Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-J).

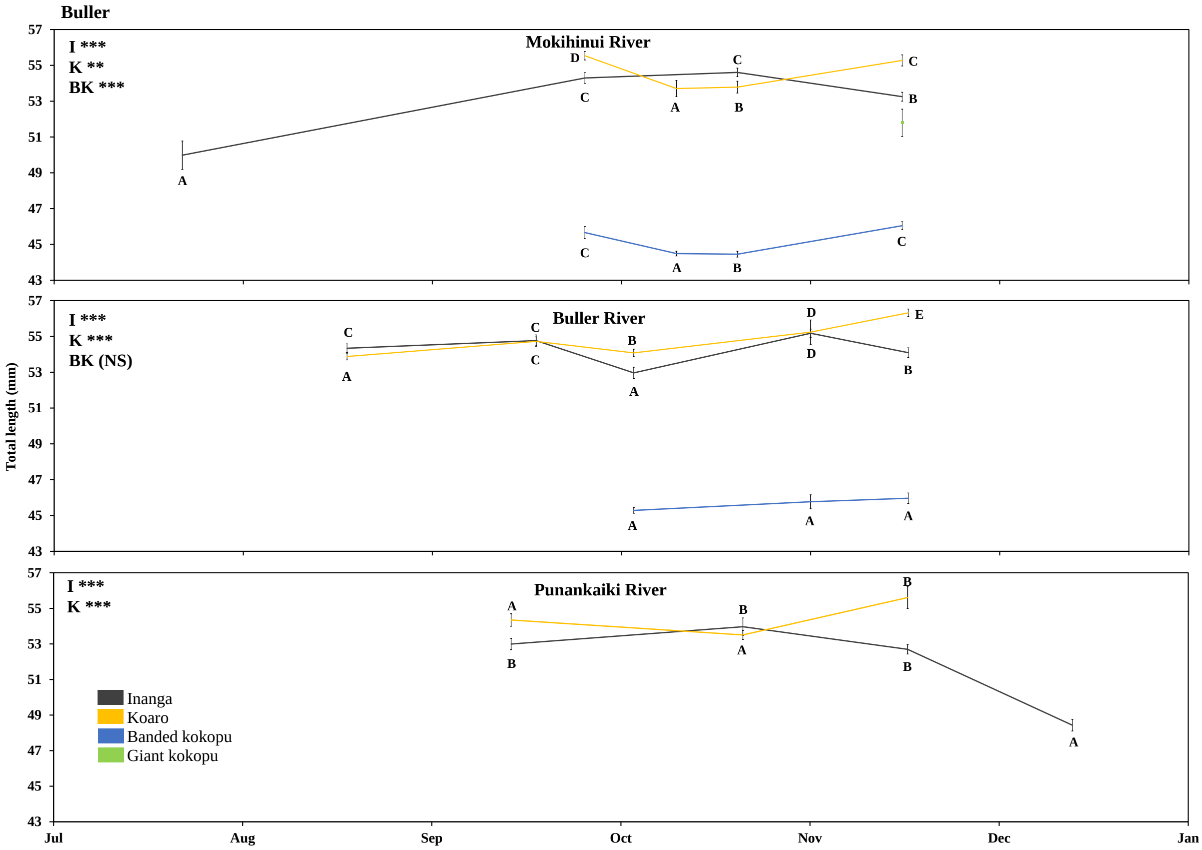


Figure 4.15. Mean total length (±SE) of whitebait species in samples collected between July and December from 3 rivers in Buller (West Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-D).

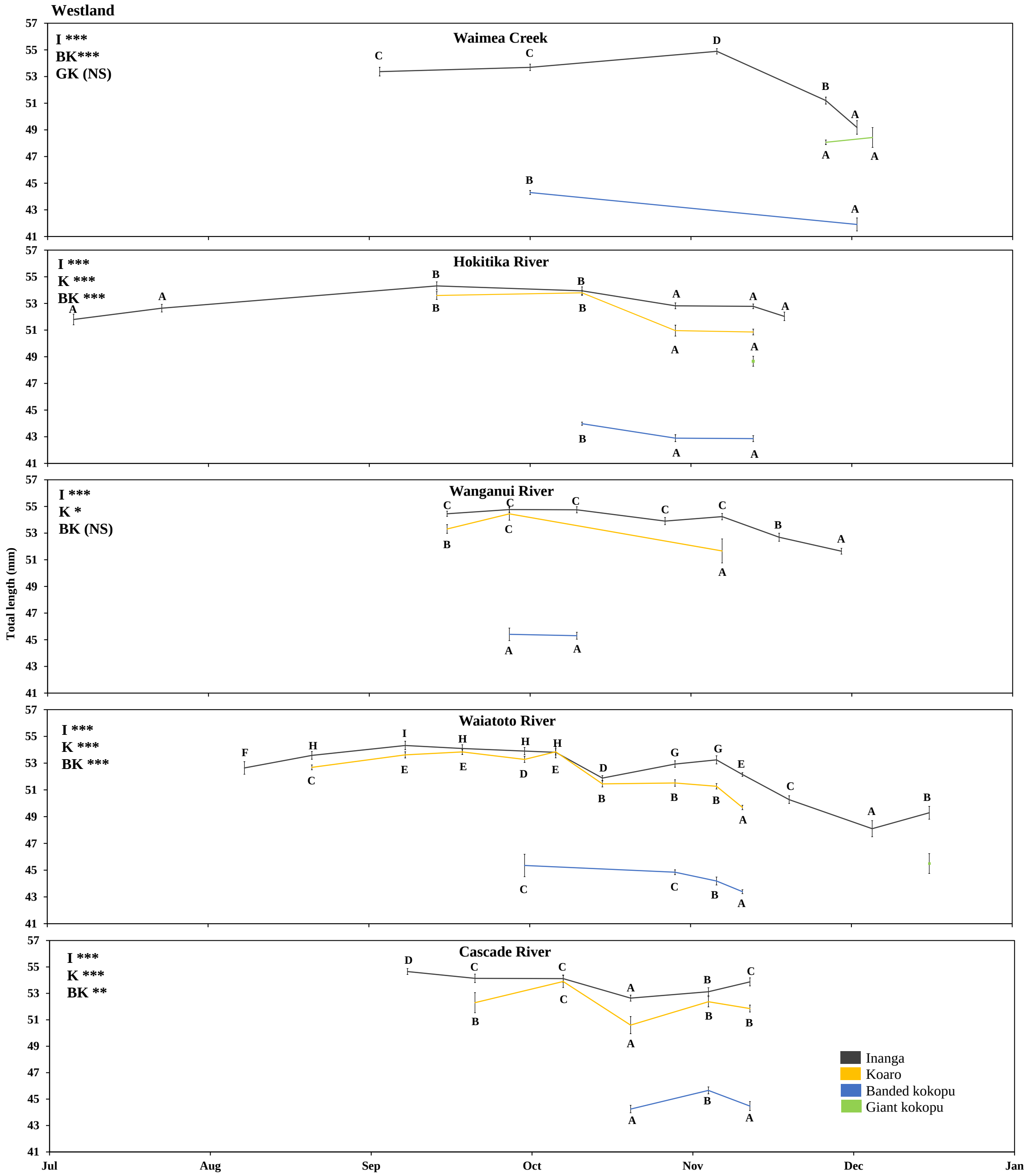


Figure 4.16. Mean total length (±SE) of whitebait species in samples collected between July and December from 5 rivers in Westland (West Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-H).

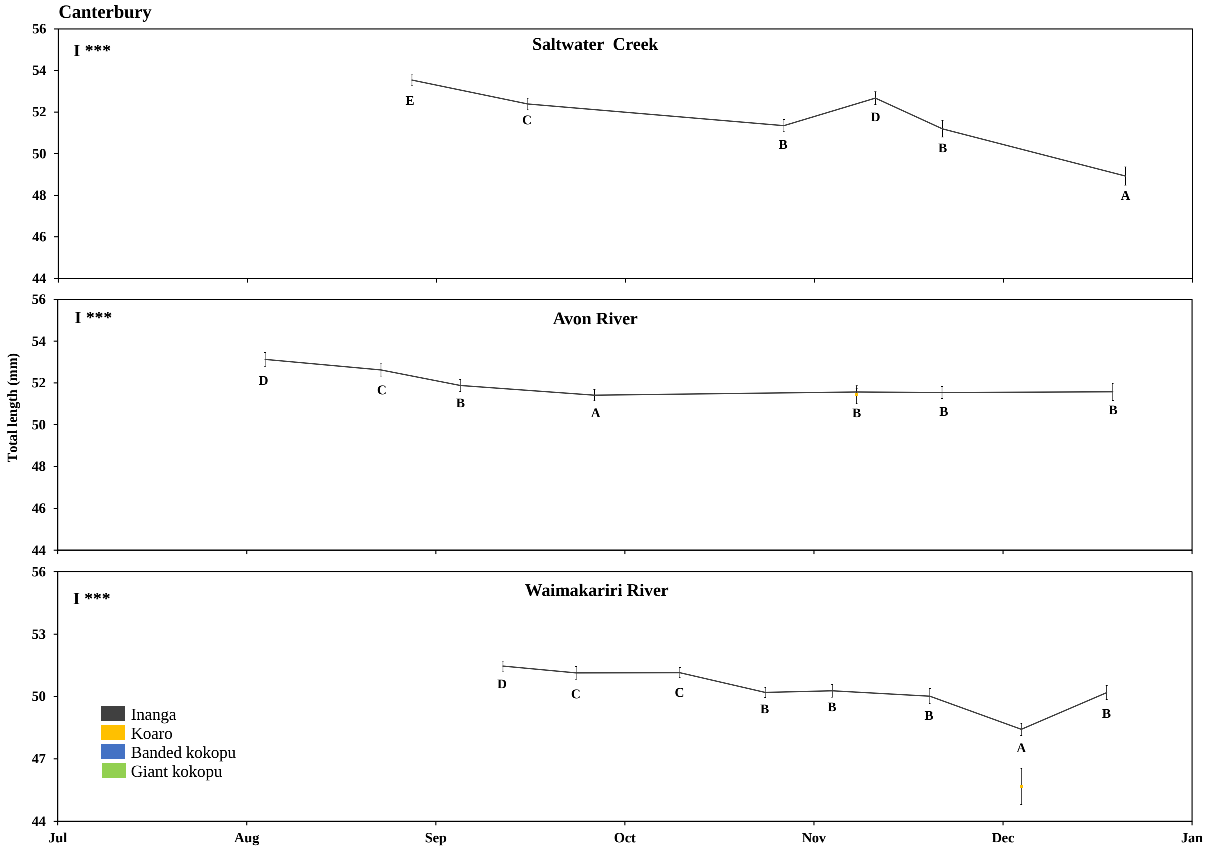


Figure 4.17. Mean total length (±SE) of whitebait species in samples collected between July and December from 3 rivers in Canterbury (South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-E).

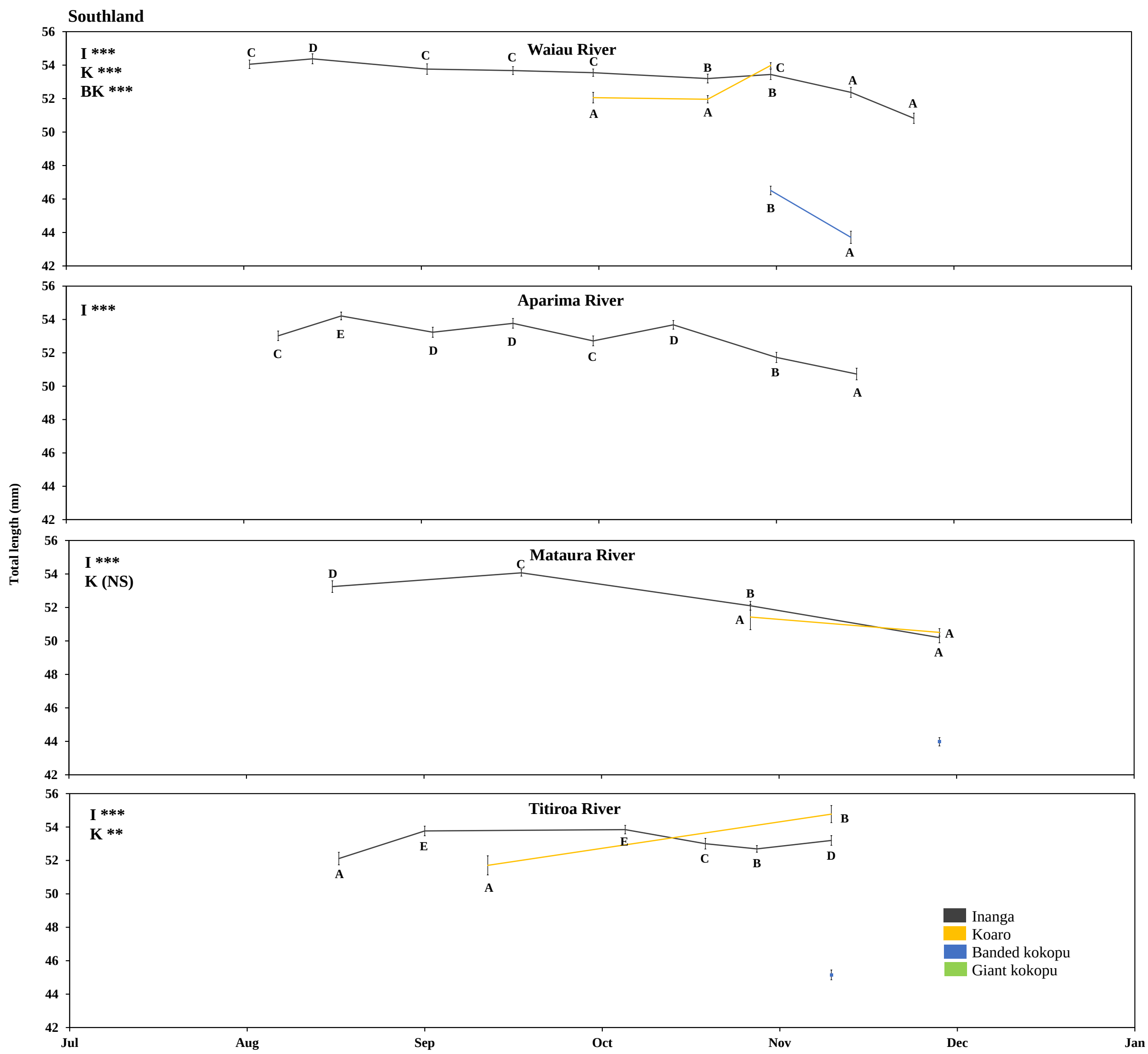


Figure 4.18. Mean total length (±SE) of whitebait species in samples collected between July and December from 5 rivers in Southland (South Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-E).

Similar to total length, there were significant differences in the condition of inanga in all 25 rivers sampled temporally throughout the country from July to December. Furthermore, the condition of koaro was significantly different in 11 of 16 rivers, and banded kokopu in 10 of 15 rivers (Fig. 4.19 to 4.25; Appendix 5, Table A5.2). Giant kokopu were only observed in two rivers temporally but changes between samples were not significant.

Inanga Condition

Clear patterns of inanga condition were seen on most rivers with the mean condition of fish starting low, gradually increasing and then decreasing. For example, on the Kaituna River (Bay of Plenty) the condition of fish started low in July at 76.1 and continually increased to reach a peak of 107.6 (5 November) and then decreased to 89.5 (18 November) (Fig. 4.20). Similarly, on the Buller River (Buller) fish increased from 92.1 (18 August) to 109.8 (2 November) and decreased to 87.3 just over two weeks later (18 November) (Fig. 4.22).

In some rivers there were higher fluctuations in condition between samples than others. For example, on the Awakino River (Waikato) the condition of fish was consistent from 17 August to 1 November (Fig. 4.19) while on the Takaka River (Tasman-Nelson) and Waiau River (Southland) there were significant fluctuations in fish condition between samples (Fig. 4.21 & 4.25).

Of interest was an increase in mean inanga condition on Saltwater Creek and Waimakariri River (Canterbury) throughout the season and then in mid-November a large decrease in fish condition followed by a large increase (Fig. 4.24).

Koaro Condition

On most rivers where koaro were present mean condition of fish in samples followed a similar trend to inanga. For example, on the Whakatane River (Bay of Plenty) there was a significant increase in mean condition of inanga and koaro in September and November and on the Waiatoto River (Westland) koaro are followed the same trend in all 9 samples from August to November (Fig. 4.20 & 4.23).

On the other hand, on the Cascade River (Westland) koaro and inanga decreased significantly in condition from 21 October to 5 November then increased significantly while inanga continued to increase in condition from 21 October to 5 November and then decrease (Fig. 4.23).

Some rivers showed no significant variability in mean condition of koaro between samples. For example, in the Waiau River (Southland) from 3 samples in September to October condition varied from 79.9 to 83.3 and in the Wainui River (Tasman-Nelson) condition varied from 90.4 to 96.4 in September and October (Fig. 4.21 & 4.25).

Banded kokopu Condition

Banded kokopu were observed in whitebait samples from rivers over a much shorter time frame than inanga or koaro. Banded kokopu mean condition showed similar patterns to that of inanga and koaro. For example, in samples from Waikato, Rangitikei, and Takaka Rivers where banded kokopu were caught in several samples, condition increased and decreased consistently with koaro and banded kokopu (Fig. 4.19 & Fig. 4.21).

In Buller the mean condition of banded kokopu decreased rapidly on rivers later in the sampling. For example, on the Mokihinui and Buller Rivers there was a significant decrease in condition from October to November (Mokihinui = 21 October 109.4 to 83.0 17 November; Buller = 4 October 119.6 to 96.1 18 November) (Fig. 4.22). On the other hand, in Westland the mean condition of banded kokopu was consistent between samples in 4 of 5 rivers. For example, on the Waiatoto River condition fluctuated between 105.8 and 108.7 in all four samples from October and November and on the Hokitika River from 102.5 to 105.7 in 3 samples from October to November (Fig. 4.23).

Giant kokopu Condition

Giant kokopu were only found in the Waikato River (Waikato) and Waimea Creek (Westland) in great enough numbers to analyse temporal changes between samples. In both cases there was no significant change in the mean condition of giant kokopu.

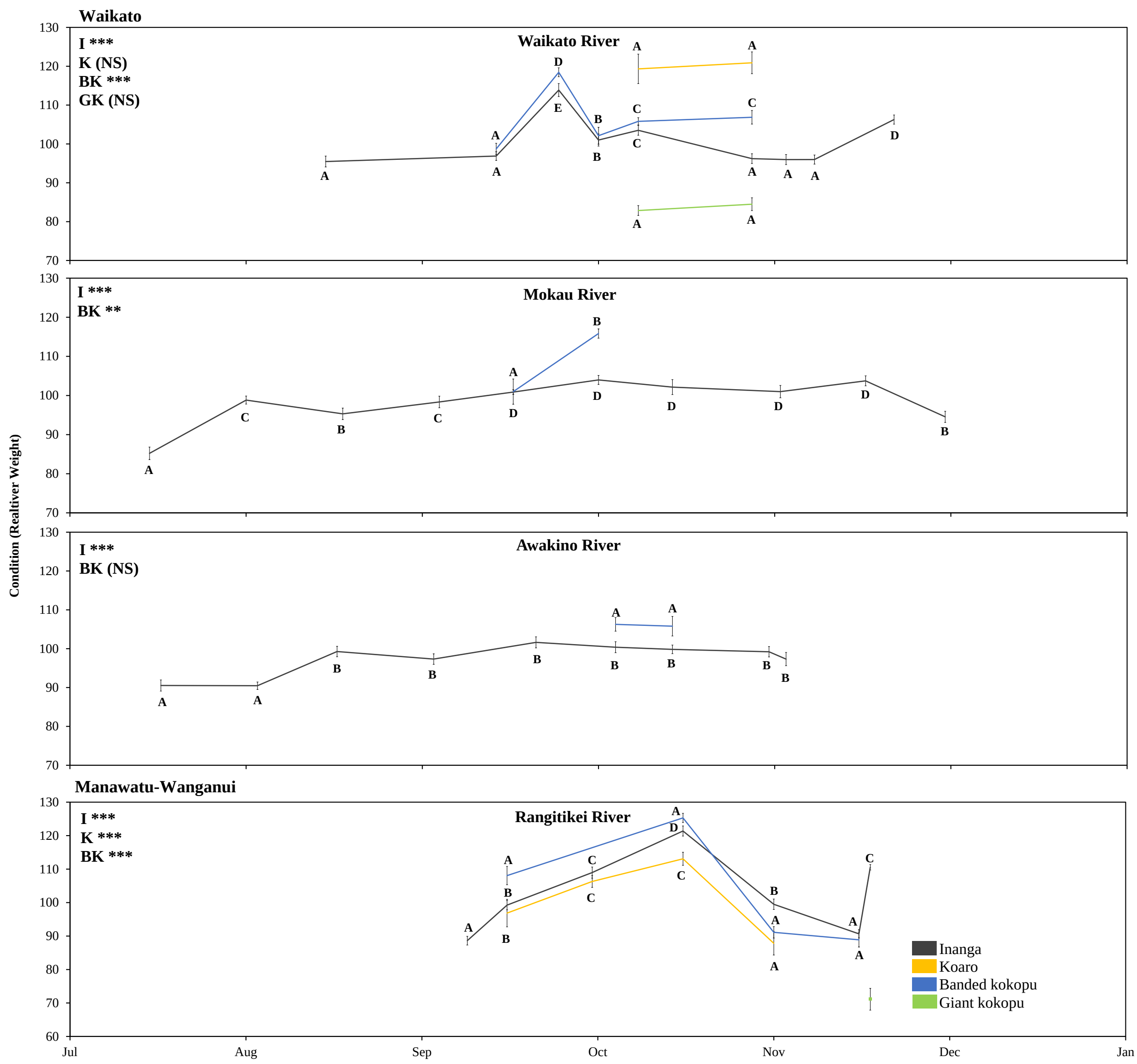


Figure 4.19. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from four rivers in Waikato and Manawatu-Wanganui (West Coast, North Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-E).

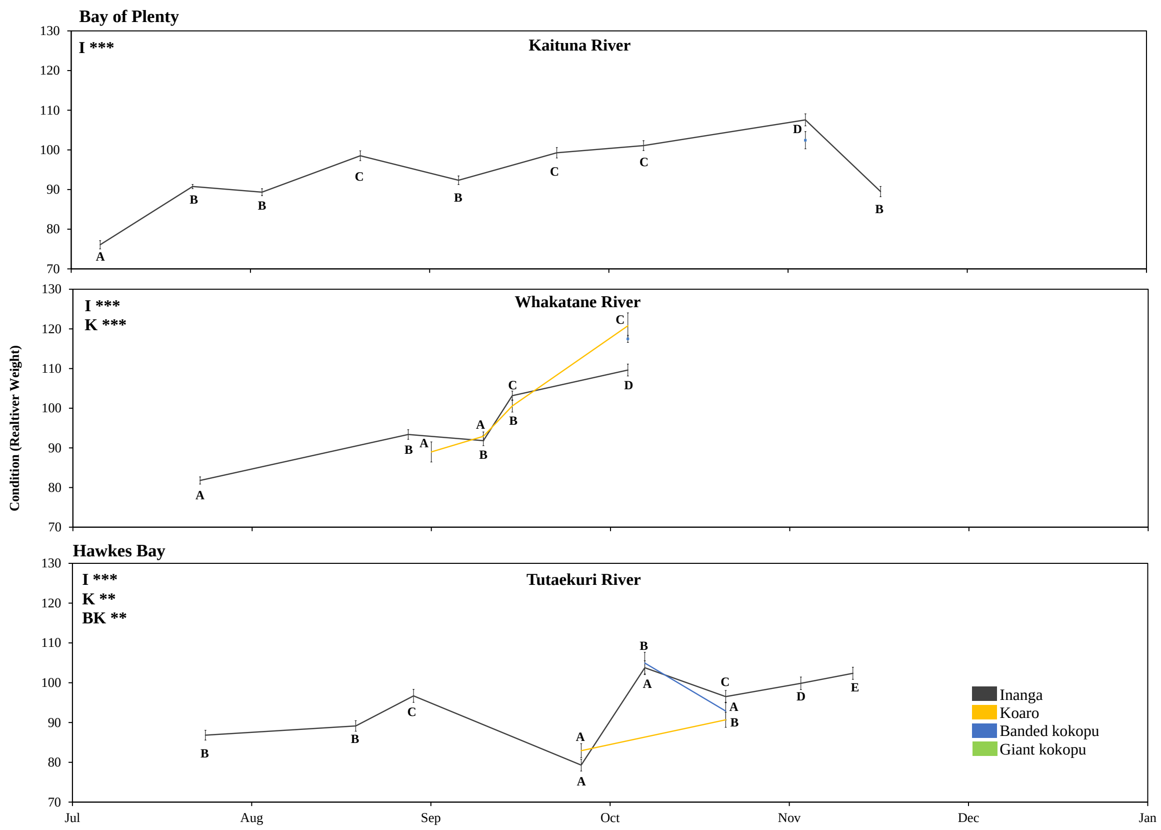


Figure 4.20. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 3 rivers in Bay of Plenty and Hawkes Bay (East Coast, North Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-D).

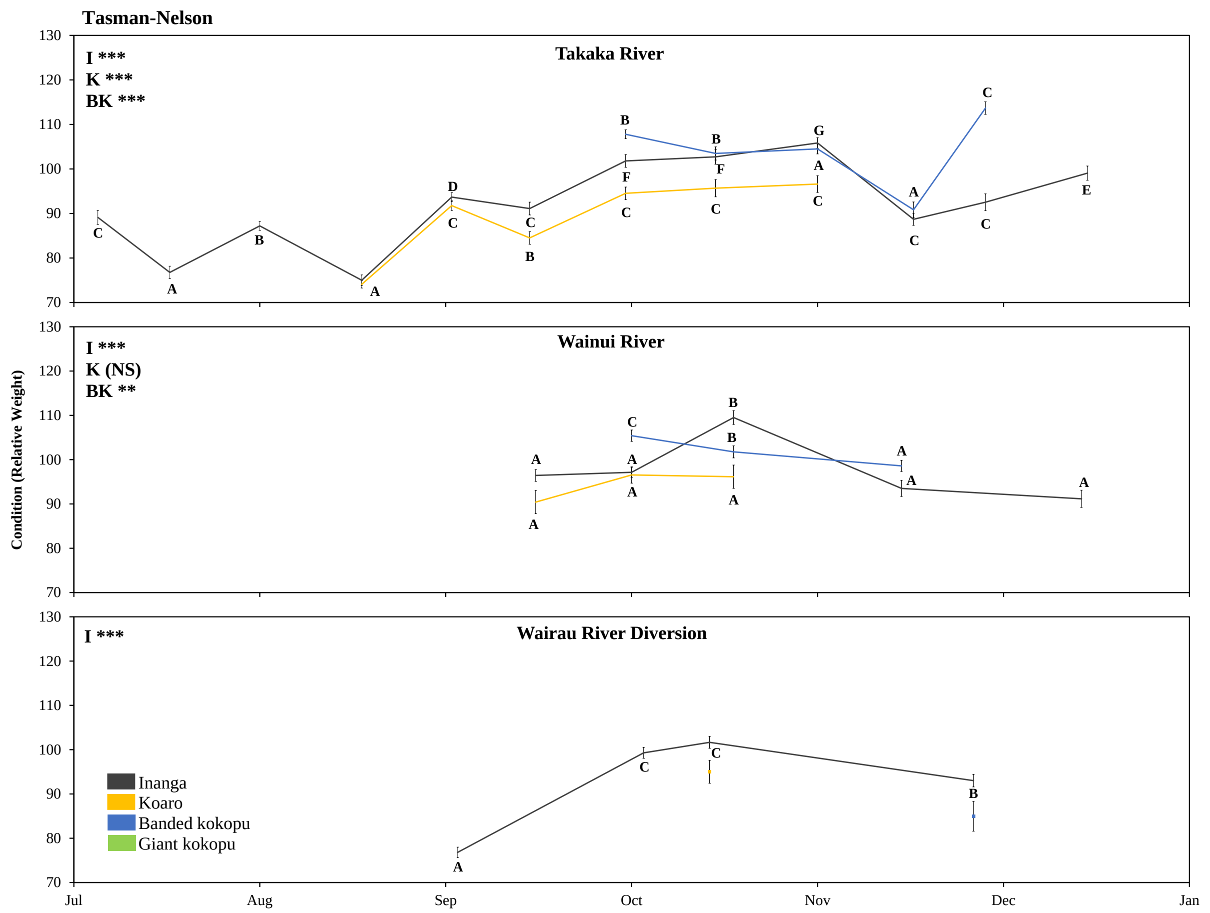


Figure 4.21. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 3 rivers in Tasman-Nelson and Marlborough (North Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-F).

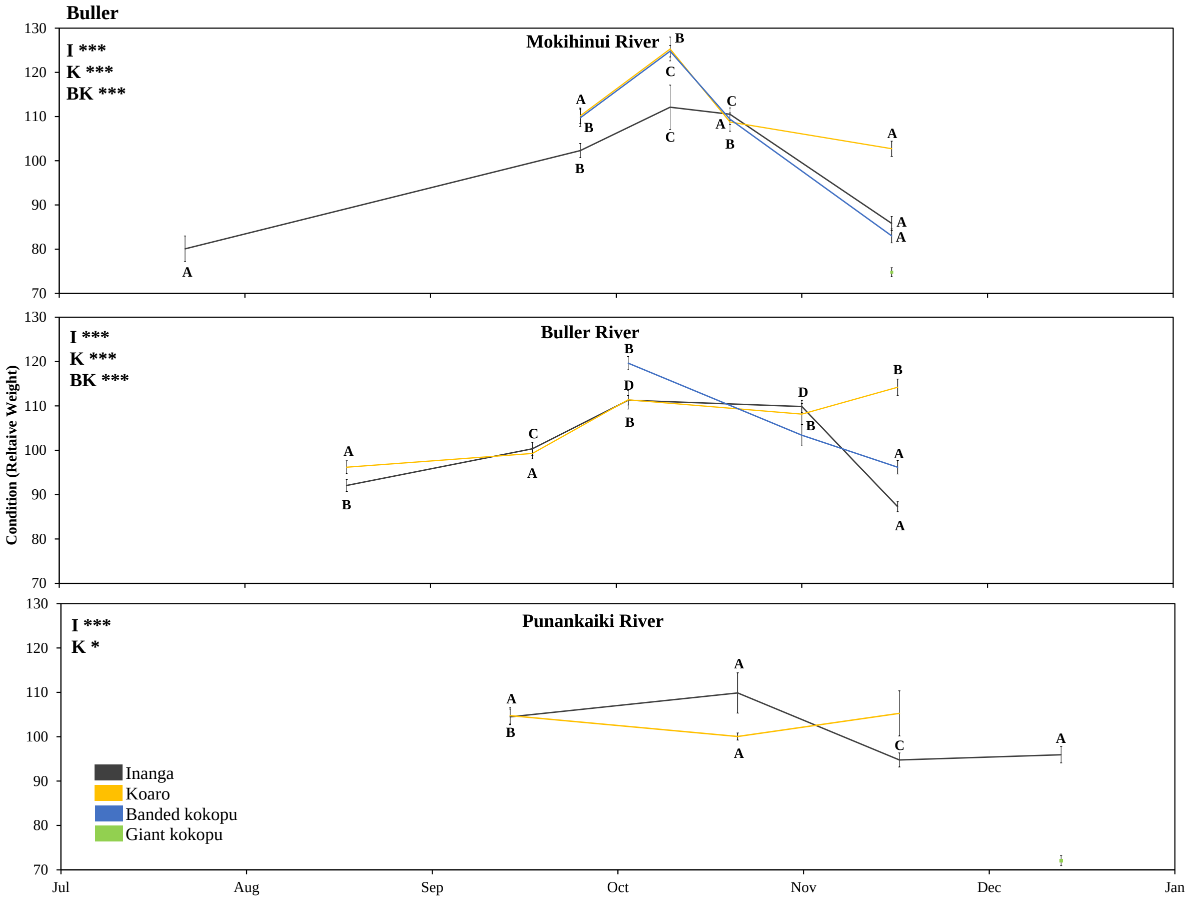


Figure 4.22. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 3 rivers in Buller (West Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-C).

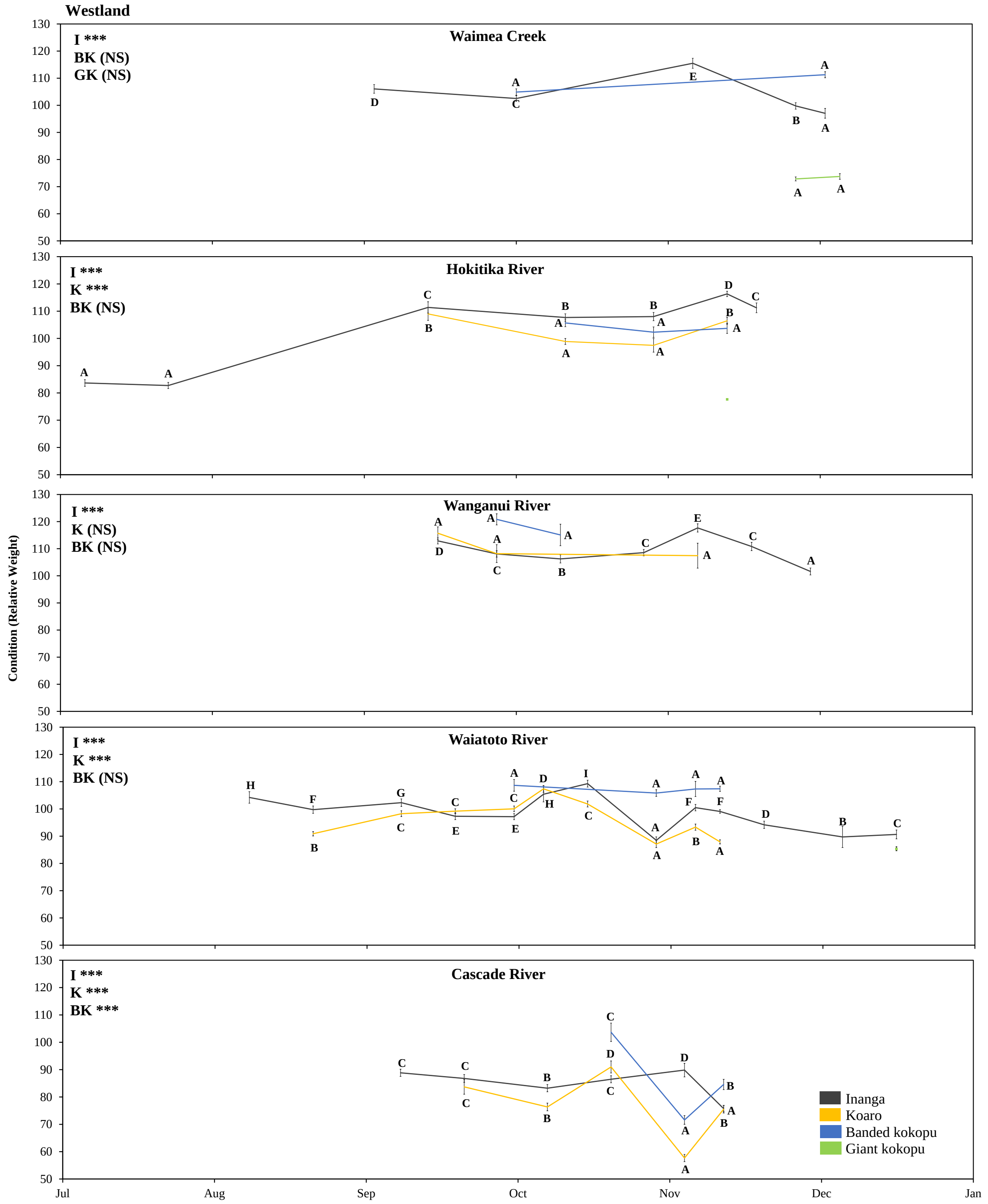


Figure 4.23. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 5 rivers in Westland (West Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-I).

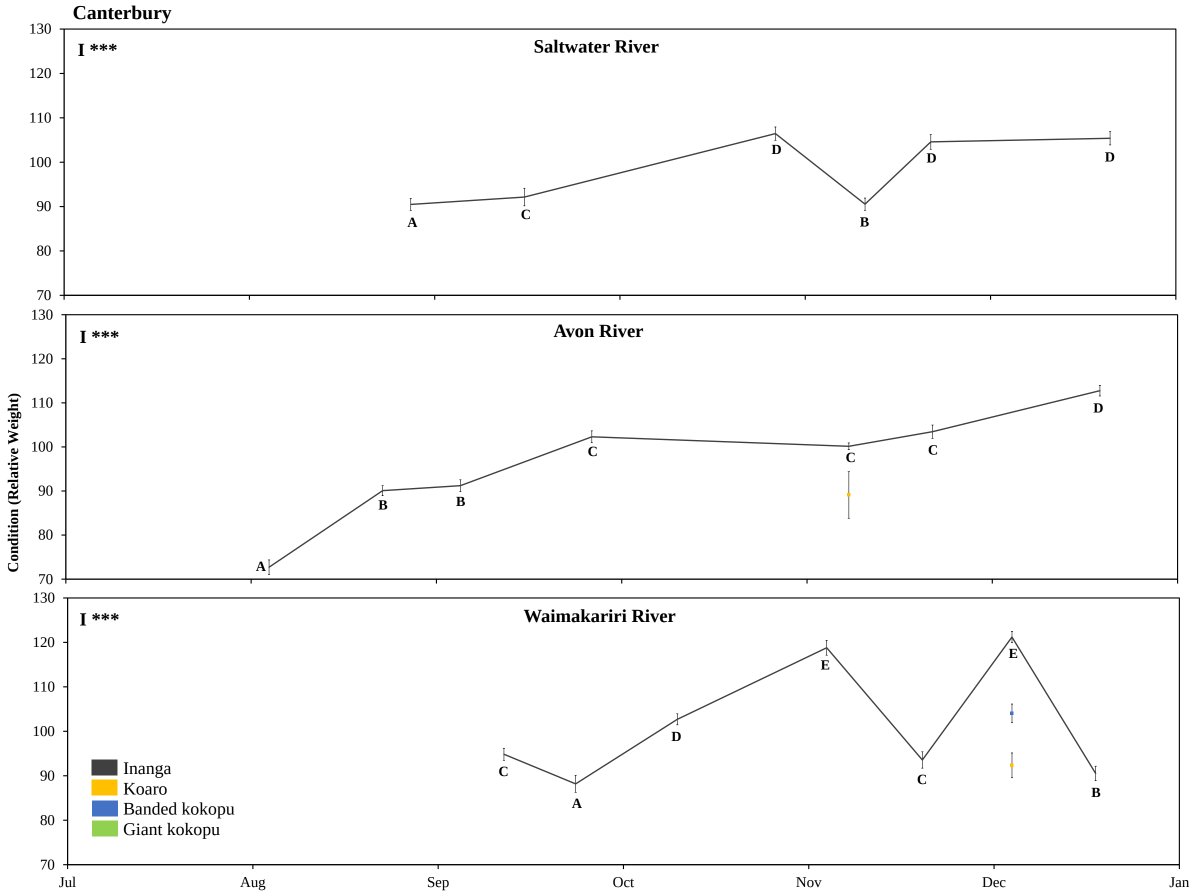


Figure 4.24. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 3 rivers in Canterbury (South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-E).

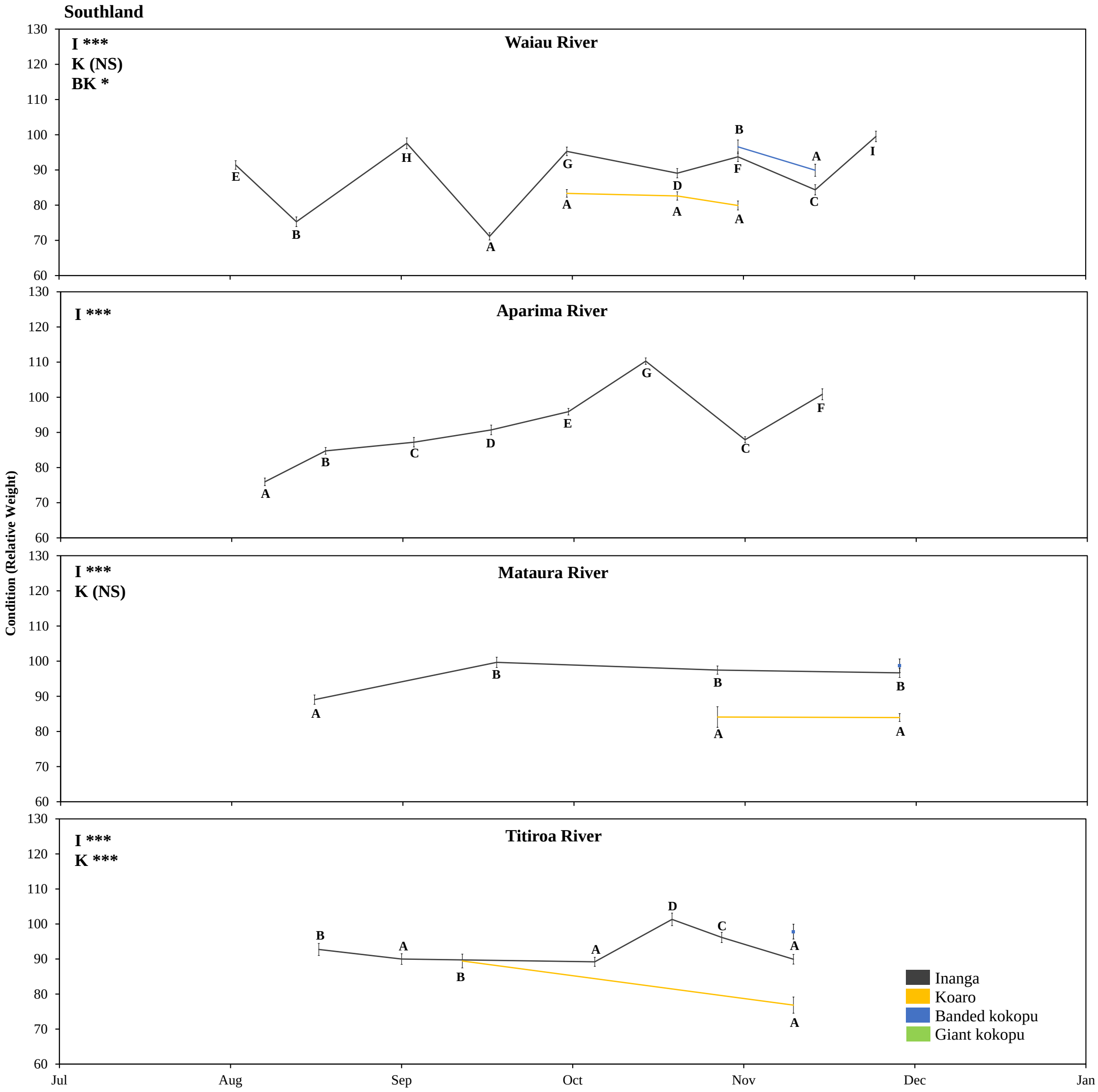


Figure 4.25. Mean condition (relative weight) (±SE) of whitebait species in samples collected between July and December from 5 rivers in Southland (South Coast, South Island). Summary of ANOVA results for each species are shown: I = inanga, K = koaro, BK = banded kokopu, GK= giant kokopu; NS = not significant, * p<0.05, ** p<0.01 and, *** p<0.001; and post hoc tests (A-I).

4.3.2 Variation between years

In 2015, whitebait samples from the Waikato River (Waikato) had high proportions of banded kokopu in September and October (3-38% in 6 samples), but in 2016 they were largely absent (1 – 1.5% in 2 samples). In October 2016, one sample contained 20% koaro but in 2015 the highest proportion of koaro recorded was 3% (Fig. 4.26).

On the Kaituna River (Bay of Plenty), inanga made up the highest proportion of all whitebait samples in both years, but there were changes in proportion of banded kokopu. In 2016, September samples had high proportions of banded kokopu (17-30%, two samples) in comparison to 2015 (0.5%, one sample) (Fig. 4.26).

On the Waimakariri River (Canterbury) there was little change between years in species composition of whitebait samples. Inanga made up ≥ 98% of all samples across both years with only small proportions of banded kokopu and koaro in November and December. Similarly, on the Waiau River (Southland) species composition was consistent between years with comparable proportions of koaro and banded kokopu found in samples during October and November. However, the peak timing of migration for koaro appeared to be earlier in 2016 (September) than in 2015 (October) (Fig. 4.27).

The only river with a statistical difference in species composition between years was the Waiatoto River (Westland) (Table 4.7). Univariate analysis found that these differences were due to higher proportions of inanga and lower proportions of koaro in 2016 samples (Fig. 4.27 & Table 4.8)..

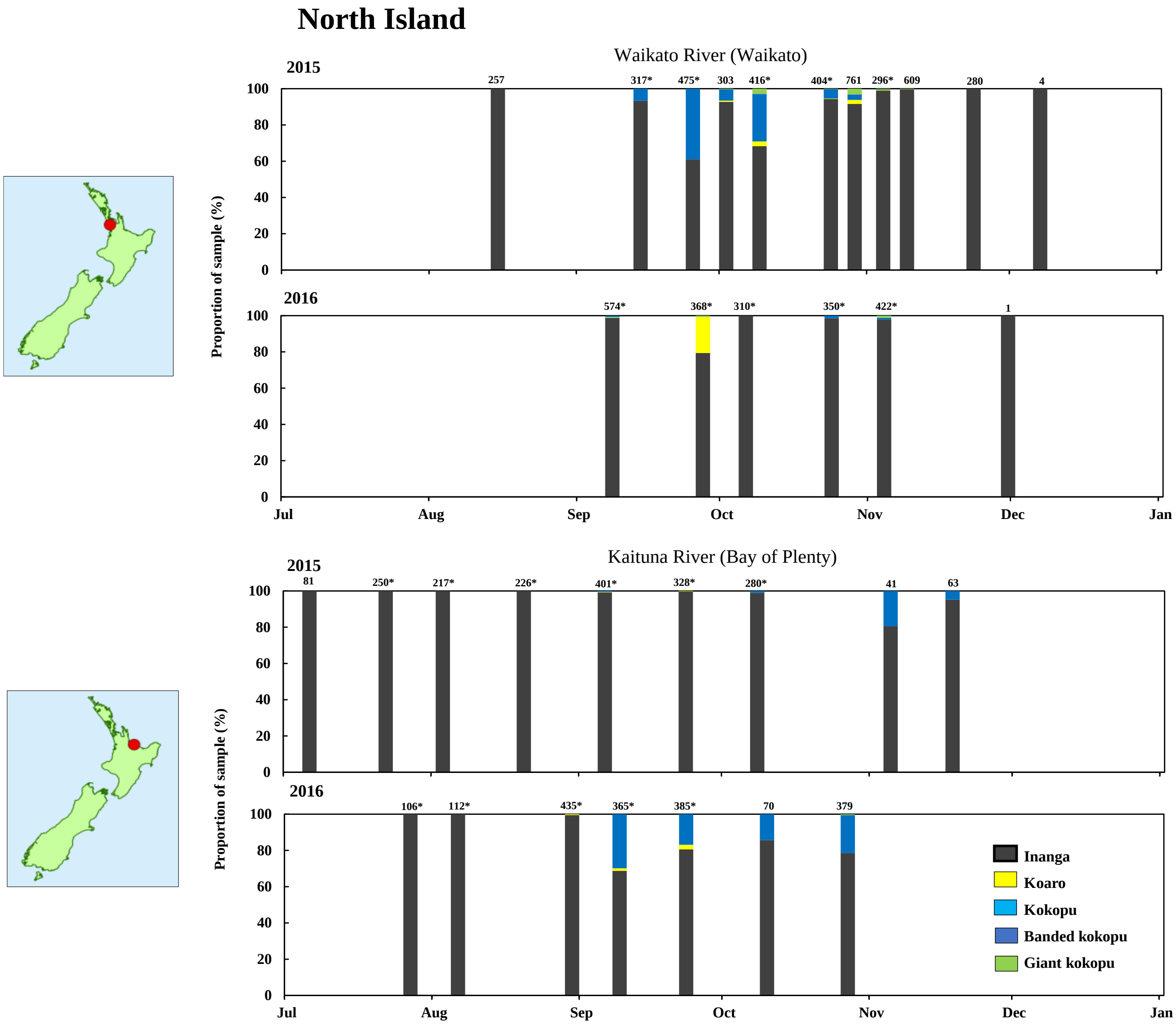


Figure 4.26. Comparison of 2015 and 2016 species composition of whitebait samples from two rivers in the North Island of New Zealand. Samples sizes are shown above data points.

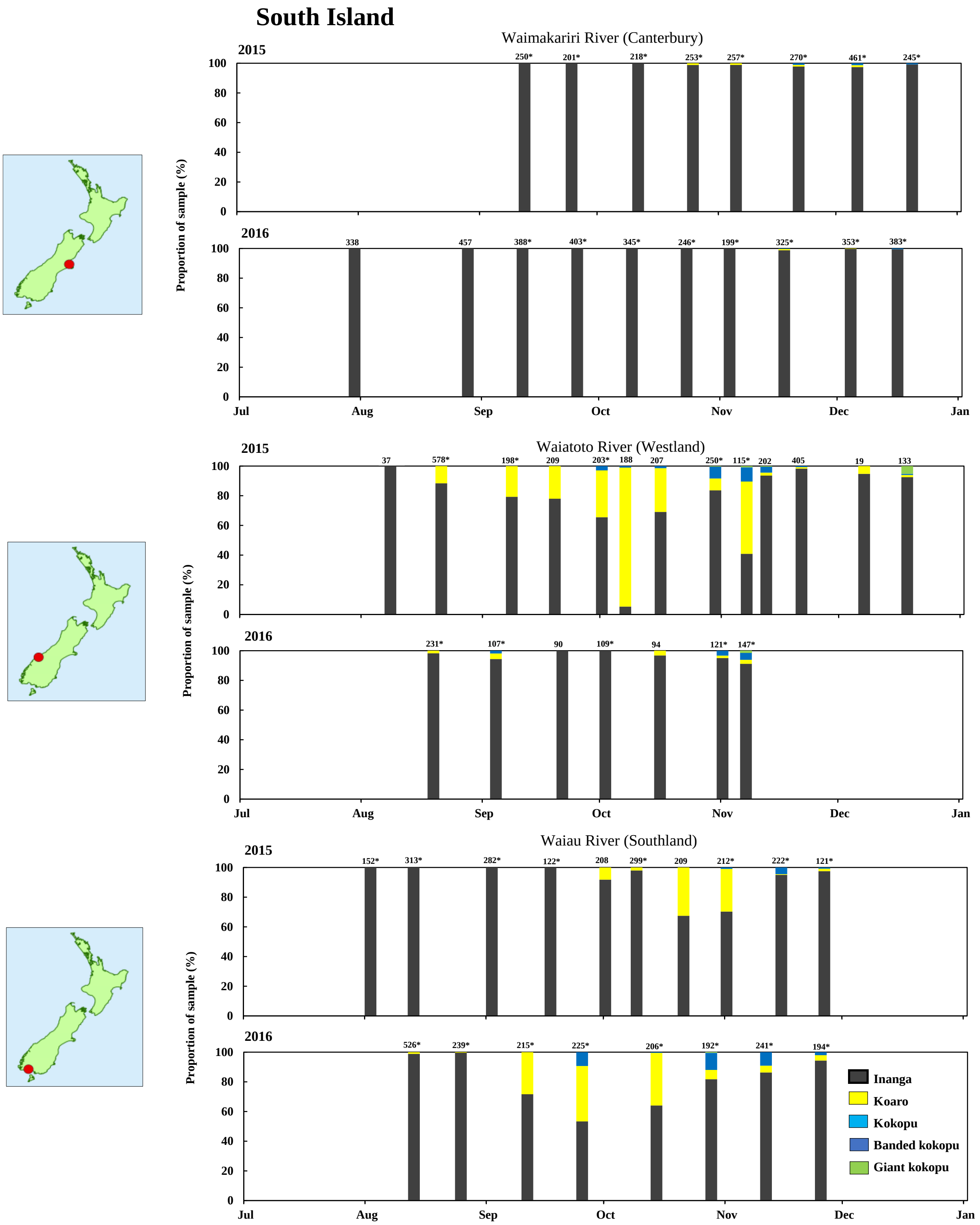


Figure 4.27. Comparison of 2015 and 2016 species composition from 3 rivers in the South Island of New Zealand. Samples sizes are shown above data points.

Table 4.7. Results from multivariate PERMANOVA of the species composition of whitebait samples from five rivers in 2015 and 2016.

Region	River	SS	Degrees of freedom	Pseudo-F	P
Waikato	Waikato River	550.67	1,	2.8151	0.11
Bay of Plenty	Kaituna River	248.19	1,8	2.3695	0.28
Canterbury	Waimakariri River	2.2065	1,14	3.4597	0.09
Westland	Waiatoto River	1502.1	1,8	7.5074	<0.01
Southland	Waiau River	709.82	1,14	3.2871	0.08

Table 4.8. Results from ANOVA comparing the proportion of individual whitebait species in samples from five rivers sampled in 2015 and 2016. Individual temporal samples were treated as replicates.

Region	River	Species	SS	Degrees of freedom	F	P
Waikato	Waikato River	Inanga	343.08	1,8	1.83	0.21
		Koaro	0.04	1,8	0.23	0.65
		Banded kokopu	548.51	1,8	4.06	0.08
		Giant kokopu	0.21	1,8	0.23	0.64
Bay of Plenty	Kaituna River	Inanga	251.21	1,8	2.42	0.16
		Koaro	1.50	1,8	2.39	0.16
		Banded kokopu	213.88	1,8	2.31	0.17
Canterbury	Waimakeriri River	Inanga	2.2	1,14	3.7	0.08
		Koaro	0.79	1,14	3.07	0.10
		Banded kokopu	0.36	1,14	1.96	0.18
Westland	Waiatoto River	Inanga	1468.23	1,8	7.75	<0.05
		Koaro	2.02	1,8	25.81	<0.01
		Banded kokopu	11.20	1,8	0.92	0.36
		Giant kokopu	<0.01	1,8	<0.01	0.96
Southland	Waiau River	Inanga	769.4	1,14	3.94	0.07
		Koaro	443.53	1,14	2.47	0.14
		Banded kokopu	0.39	1,14	2.43	0.14

4.3.3 Variation over 50 years

4.3.3.1 Comparison of species composition from 1964 and 2015

The combined species composition of whitebait samples from all rivers in New Zealand was similar in 2015 to that of 50 years ago, but there were slightly higher proportions of kokopu species and lower proportions of inanga and koaro in 2015 (Fig. 4.28). McDowall (1965) did not separate the species of 'kokopu' whitebait, but in 2015 the vast majority of this grouping were banded kokopu (Fig. 4.28).

When whitebait samples from the North Island (both coasts), South Island (West Coast) and South Island (East Coast) were separated, there were higher proportions of koaro and banded kokopu and lower proportions of inanga in 2015 than in 1964 (Fig. 4.29). Again, banded kokopu dominated the 'kokopu' whitebait grouping in all three regions.

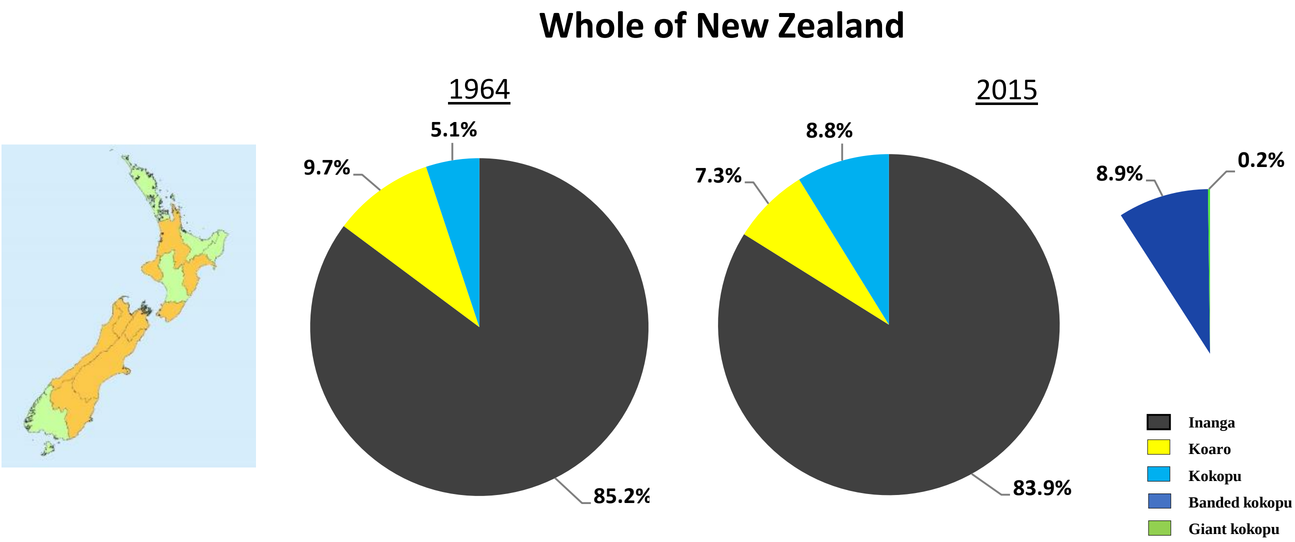


Figure 4.28. Combined species composition of whitebait samples from all rivers in New Zealand in 1964 (adapted from McDowall, 1965) and 2015. For the 2015 data the 'kokopu' whitebait segment has been further differentiated into banded and giant kokopu.

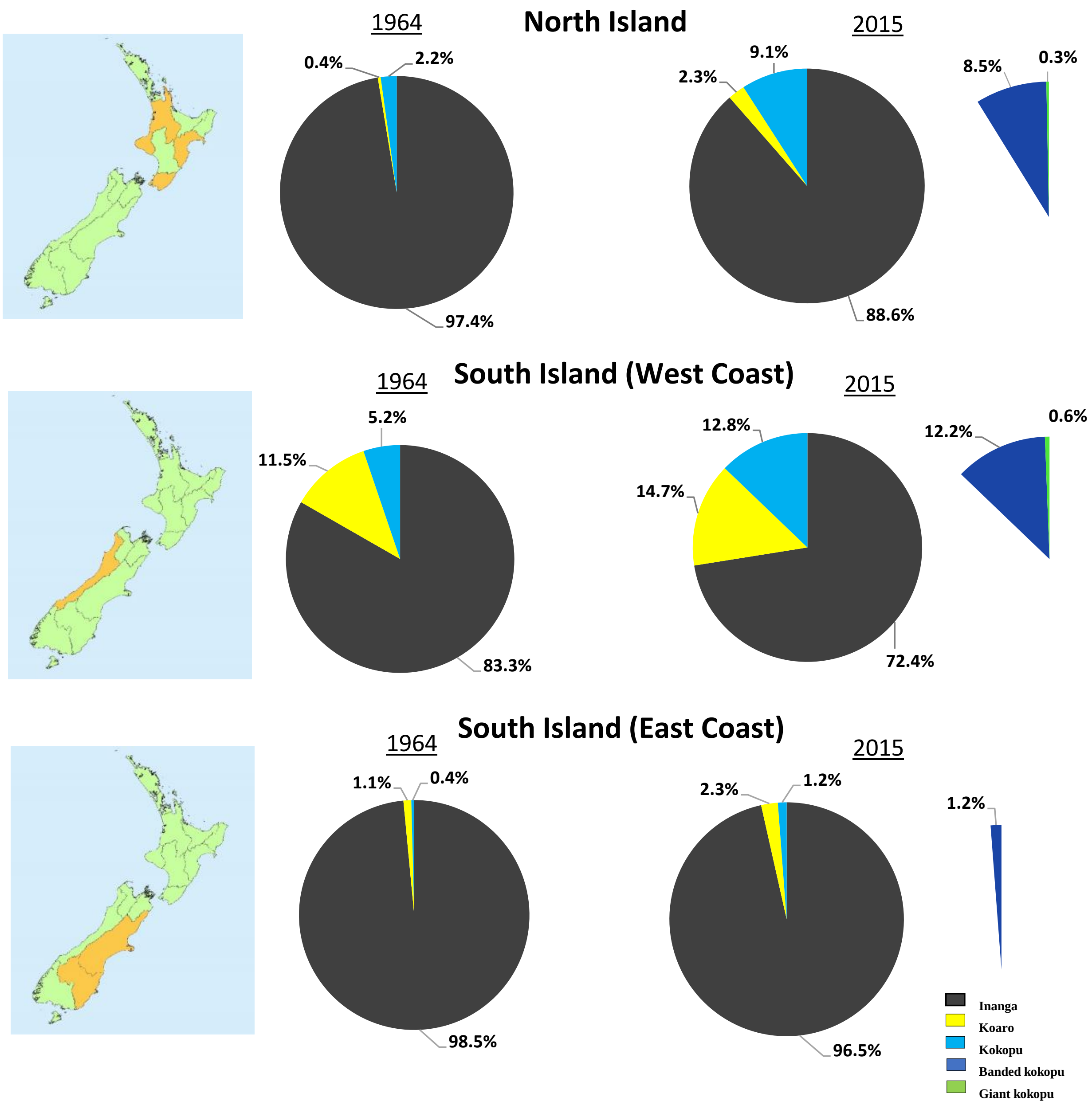


Figure 4.29. Combined species composition of whitebait samples from all rivers in the North Island (both coasts), South Island (West Coast) and South Island (East Coast) in 1964 (adapted from McDowall, 1965) and 2015. For the 2015 data the 'kokopu' whitebait segment has been further differentiated into banded and giant kokopu. Note the North Island data excludes the Waikato River.

4.3.3.2 Comparison of whitebait species composition in 1981 to 1983 and 2015/2016 in Bay of Plenty Rivers

The overall species composition of whitebait samples from the Kaituna River (Bay of Plenty) was very different in 2105/2016 compared to what was seen in the 1981-1983 samples. In 2015/2016, there were higher proportions of banded kokopu than in 1981-1983 and much lower proportions of koaro (Fig. 4.30 & 4.31; Table 4.9)

The species composition of whitebait samples from the Rangitaiki River was similar between years with at least 95% inanga and 2% banded kokopu in samples in both years, but no koaro were found in 2015.

On the Whakatane River, there were higher proportions of koaro and banded kokopu in samples from 1981-1983 than in samples from 2015. In 2015, a single shortjaw kokopu was observed in a sample, but this species was not found in 1981-1983. Similarly, in 1981-1983 there were higher proportions of koaro and banded kokopu in samples from the Whangaparoa River than in 2015 (Fig. 4.31; Table 4.9).

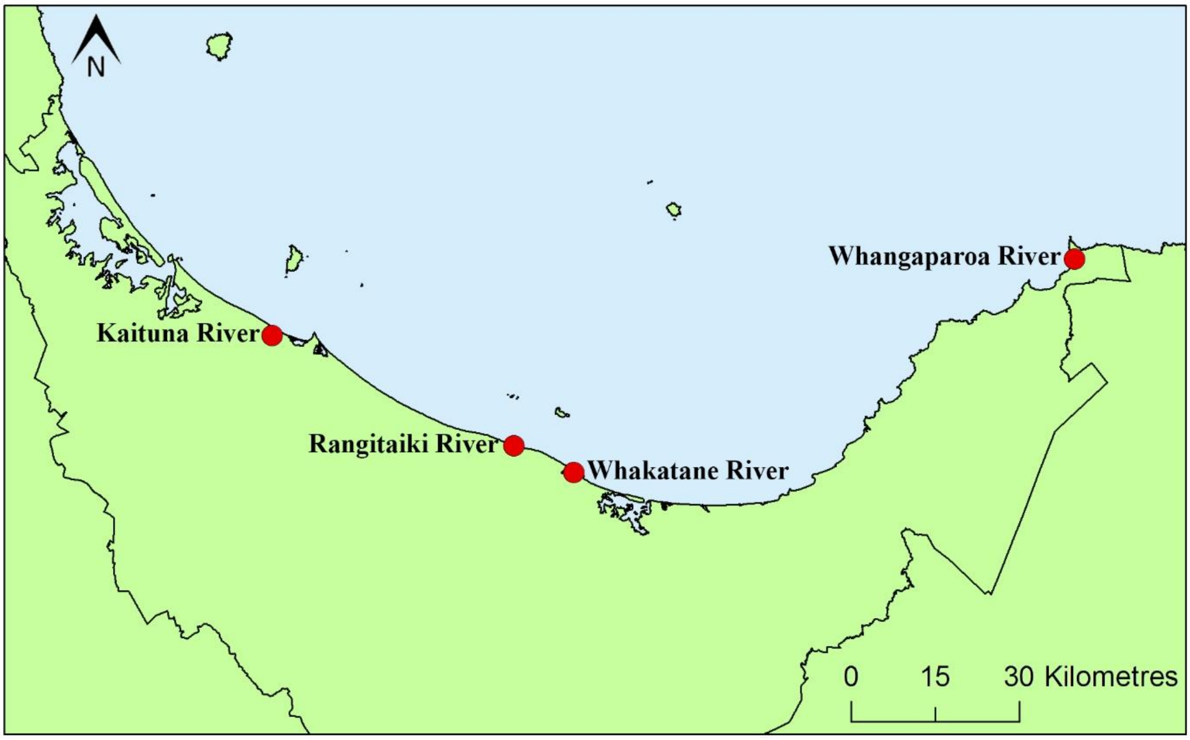


Figure 4.30. Locations of 4 Bay of Plenty rivers sampled in 1981-1983 (adapted from Rowe et al, 1992) and in 2015 (and 2016 for Kaituna River only).

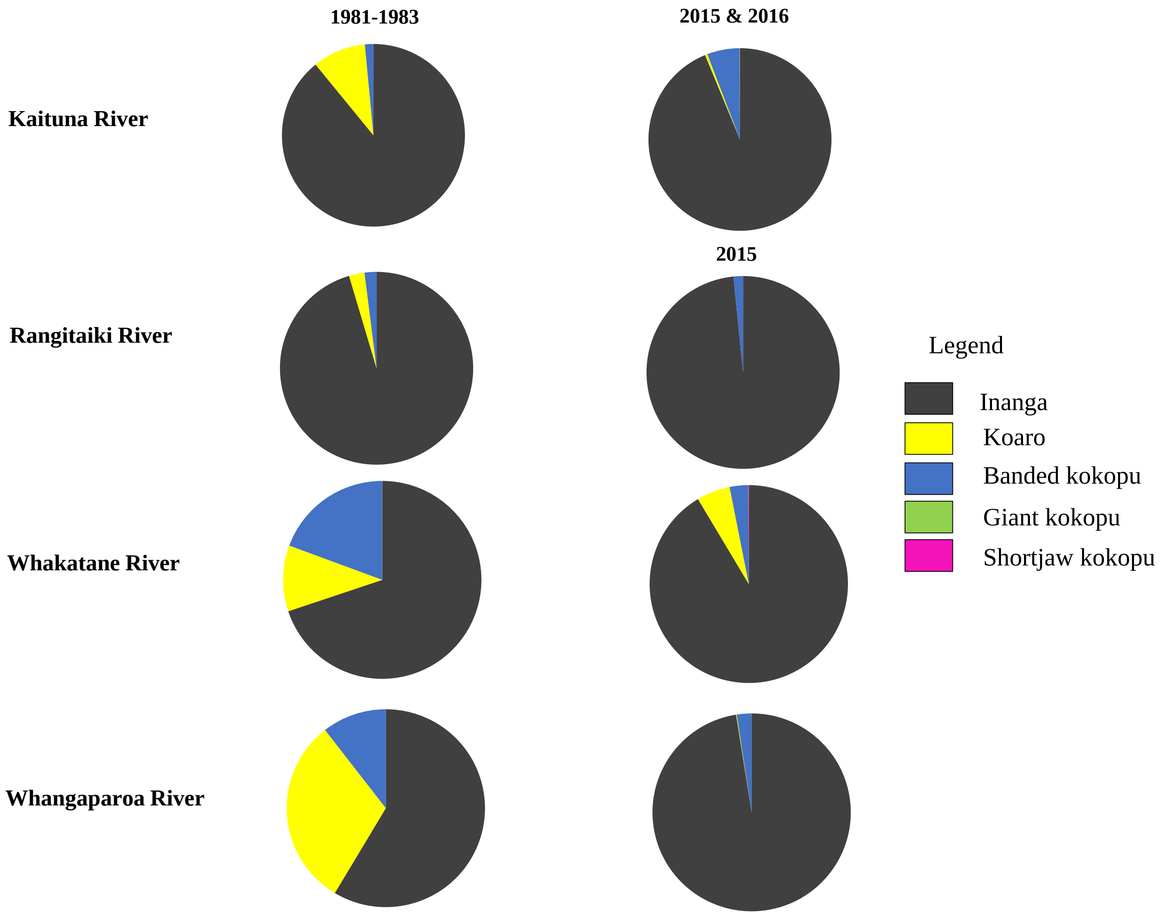


Figure 4.31. Species composition of whitebait samples from four Bay of Plenty rivers in 1981-1983 (adapted from Rowe et al, 1992) and in 2015 (and 2016 for Kaituna River only).

Table 4.9. Species composition of whitebait samples from four Bay of Plenty Rivers in 1981-1983 (Adapted from Rowe et al, 1992) and in 2015 (and 2016 for Kaituna River only). Standard Error in brackets for 2015/2016 sampling.

		Species Composition				
River	**Year**	**Inanga**	**Koaro**	**Banded kokopu**	**Giant kokopu**	**Shortjaw kokopu**
Kaituna River	1981-1983	89.1	9.4	1.5	0.0	0.0
	2015 & 2016	93.8 (3.2)	0.4 (0.2)	5.8 (3.0)	0.0	0.0
Rangitaiki River	1981-1983	95.5	2.6	2.0	0.0	0.0
	2015	98.4 (1.6)	0.0	1.6 (1.6)	0.0	0.0
Whakatane River	1981-1983	70.0	10.8	19.4	0.0	0.0
	2015	91.4 (3.2)	5.5 (2.0)	3.0 (2.7)	0.0	0.1 (0.1)
Whangaparoa River	1981-1983	58.6	30.9	10.5	0.0	0.0
	2015	97.5 (2.2)	0.1 (0.1)	2.4 (2.1)	0.0	0.0

4.3.3.3 <u>Comparison of morphology data from 1969 to 1972 and 2015 to 2016</u>

Historical data from 1969-1972 of inanga (from McDowall & Eldon, 1980) show daily and yearly fluctuations in inanga mean lengths (Fig. 4.32). In early September, inanga whitebait increased in length across all years. In 1971 and 1972, whitebait were smaller in September (ca.52mm) than those in both 2015 and 2016 (ca. 54mm)

A peak at the start of October followed by a decline in November is evident across all years. In 1970, the decline began about 6 November with mean lengths of 54.7mm eventually down to 50.3mm, and in 1971 the decline occurred about 30 October (McDowall & Eldon, 1980). Similarly in 2015, the decline occurred around 7 November from 53.2mm eventually down to 48.1mm. There were too few samples taken in 2016 to pinpoint the exact date of the decline in total length, but the mean length of inanga dropped from 54.7mm to 50.0mm.

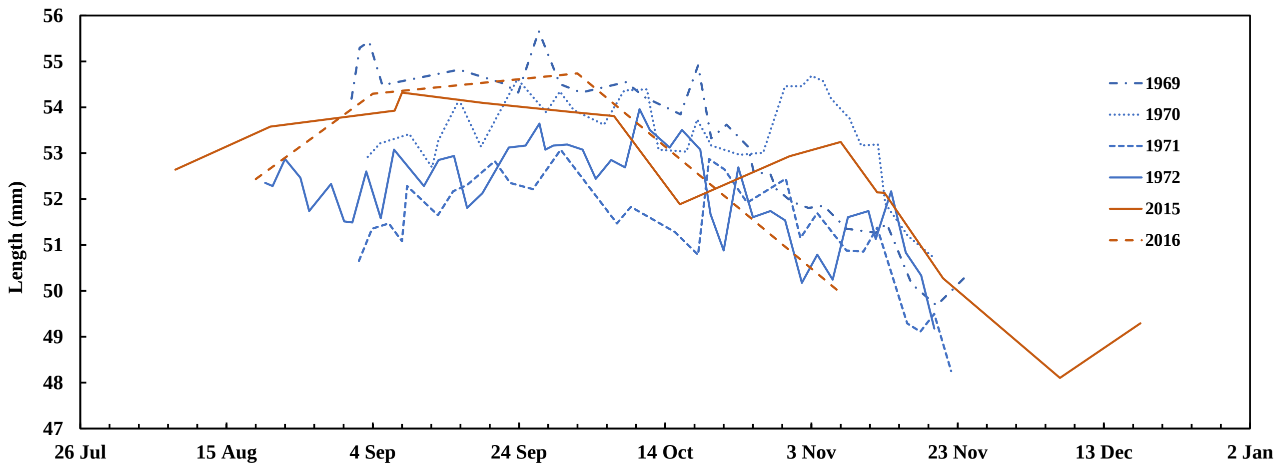


Figure 4.32. Comparison of inanga length on the Waiatoto River (Westland) from 2015 and 2016 (orange) to historical data from 1969 to 1972.

4.4 DISCUSSION

4.4.1 Variation during 6 months of whitebait migrations

4.4.1.1 Composition

The species composition of whitebait samples was found to change from July to December with variability seen among regions, among rivers in regions and within rivers.

Whitebait samples from rivers in Hawkes Bay, Marlborough, Canterbury, and Otago (east coast regions) were comprised of large proportions of inanga, but Tasman-Nelson, Buller, Westland, Southland (mainly west coast regions) comprised high proportions of non-inanga species at some stage during the 6 months sampling period. As discussed in Section 3.4.1, the regional distribution of adults of the five whitebait species appears to correspond with proportions of species in samples throughout the 6 months.

There were differences in species composition between rivers in the same region. In Tasman-Nelson, Buller and Westland, whitebait samples from some rivers had higher proportions of koaro or banded kokopu. Generally, the rivers where larger proportions of koaro were observed were very large river systems (Waiatoto River, Takaka River, Buller River) while the rivers with higher proportions of banded kokopu were smaller catchments with high forest cover (Wainui Stream, and Waimea Creek). This could be a sampling artefact, but also might suggest river selection of these species. On the Wainui Stream, no whitebait were caught in July, August or the start of September, despite extensive fishing effort, and very few whitebait were caught from the end of November into December. Sampling in October and at the start of November were the only times when samples were easier to collect and this corresponded with the peak timing of banded kokopu migrations. The flow of water from this stream is very low ($2.1m^3/sec$), potentially making it more difficult for migrating whitebait to sense its freshwater plume in the coastal environment, but there may be river selection by banded kokopu in these smaller streams with bush-drained catchments and large numbers of upstream adults (Baker & Montgomery, 2001; Baker & Hicks, 2003).

Whitebait were very scarce in December in Buller and Westland, but the sparse samples contained giant kokopu. While some of these samples contained fewer whitebait (5-133 sample size), the samples were representative of the catch because they were the only whitebait migrating on that day. The Waimea Creek in particular had very high proportions of giant kokopu at the end of November and December when the mouth was open after being periodically closed for parts of the season. This small stream is situated between two much large rivers; the Taramakau and Hokitika (Westland). The Hokitika River had giant kokopu in whitebait samples, but they were in very low proportions. New Zealand freshwater fish database records show the presence of adult giant kokopu and shortjaw kokopu in the Waimea catchment (NIWA, 2015). Similarly, the catchment has high proportions of forested riparian margins (LCDB, 2017). Again, the presence of high forest cover, and adult fish in the catchment combined with high proportions of may suggest river selection of these fish (Fig. 3.21).

The timing of migration varied among the whitebait species for different parts of the country. The timing of runs of banded kokopu, giant kokopu and shortjaw kokopu whitebait were earlier in the North Island compared to the South Island. In the North Island, banded kokopu whitebait peak migrations were from mid-October to the early/mid-November. In the South Island, in Tasman-Nelson, Buller, and Westland (west coast) peak migrations were from mid-October to early November, but in Canterbury and Southland (east coast) from mid-November to early December. In previous studies, Rowe et al. (1992) observed peak migrations of banded kokopu in mid-September in the Bay of Plenty compared to mid-October in my study. McDowall and Eldon (1980) observed peak migrations of banded kokopu in mid-November in Westland compared to mid-October to early November in my study.

The first migration of giant kokopu whitebait occurred during late September and in October on North Island west coast rivers, from mid-October for Tasman-Nelson rivers and from early November for Buller and Westland rivers. These timings were consistent with the findings of McDowall (1999) who found giant kokopu whitebait migrating from November in Westland rivers and Stancliff et al. (1988) who found juvenile (pigmented) giant kokopu migrating in the Waikato River (near Huntly) from mid-October.

Shortjaw kokopu were observed in samples in early October in Bay of Plenty, mid-November in Manawatu-Wanganui and early November in Buller and Westland. The only records of shortjaw kokopu at the whitebait stage are in Cemetery Creek (a tributary of the Okarito River (Westland) on 27 November 1985 when a single fish was found (McDowall et al., 1994) and the Waikato River (Waikato) from a sample on 3 November 2002 and in the last half of October in 1998 (Cindy Baker, *pers. comm.*). Although species identifications of these fish were not confirmed genetically, they show similar temporal patterns to what was observed in my study.

The earlier migration of banded kokopu, giant kokopu, and shortjaw kokopu whitebait in the North Island may be due to differences in the temperature cues for the onset of spawning (Taylor, 2002; Stevens et al., 2016) and the shorter duration of the larval phase of fish in the North Island (Rowe & Kelly, 2009). This corresponds with the latitudinal gradients in temperature and productivity of coastal waters (Schiel, 2004). The similarities in composition and timing of species migration within rivers in regions, but differences between more distant regions suggests dispersal of banded kokopu, giant kokopu and shortjaw kokopu larvae may be less extensive than that observed for inanga (Hickford and Schiel, 2016).

The timing of koaro whitebait migration was more variable than for the other species. Koaro on the west coast of the South Island migrated from August through until December, but on the east coast migration occurred from October to December. In the North Island, koaro were found in whitebait samples between September and November. This is consistent with Rowe et al. (1992) who found koaro whitebait in higher proportions from September to November in the Bay of Plenty. Likewise McDowall & Eldon (1980) found koaro whitebait on the west coast of the South Island throughout the season, but proportions varied throughout(McDowall & Eldon, 1980).

River temperature may play a role in the timing of migration of species into rivers. The earlier migration of koaro into colder, more southern rivers correlated with the adult habitat of koaro in cool, forest covered, bouldery streams. The later migration of banded and giant kokopu correlates with the warmer smaller lowland stream where they species often persist (McDowall, 1965). The timing of peak migrations also appears to correspond with peaks in length. This is discussed in the morphology section below.

It is possible that non-inanga whitebait were migrating in very low numbers outside of the periods described above, but were not detected with a whitebait sample of only c. 200 fish. For example, in Canterbury koaro were found to migrate from October to December but only a few individuals (1-6 individuals) were observed in these samples apart from the Hapuku River. If larger (1kg) samples had been collected, koaro may have been observed outside of the periods described above, but the practicalities of collecting and sorting multiple large samples was beyond the scope of this project. Appendix 3.1 addresses potential biases in sample size and found that smaller samples did not allows detect less common species. For example, on the Avon River (Canterbury) on 9 November, 5 of 9 laboratory sub-samples contained koaro. If sample 3 had been chosen koaro would not have been detected while if sample 4 had been chosen koaro would have been detected (Appendix 3.1).

4.4.1.2 Morphology

There were significant differences in total length, body depth and condition (relative weight) of inanga, koaro and banded kokopu between months (September to November), among regions and among rivers within regions.

There were significant changes in the total length of inanga, koaro and banded kokopu, but not giant kokopu, on most rivers sampled over a six month period. There were usually lower numbers of koaro, banded kokopu and giant kokopu in samples than inanga and ≥5 whitebait per species were needed in at least two samples from a river to analyse temporal data. On all but one river, when no significant change was observed in the mean total length of koaro, banded kokopu or giant kokopu there were only two samples that could be compared. If greater numbers of non-inanga whitebait had been collected in more samples on these rivers (through collecting more or larger samples), then significant changes in mean total length may have been observed.

There were fluctuations in the mean length of whitebait between samples, but clear patterns were observed. Inanga and banded kokopu increased in mean total length and then decreased during the migration season. In studies by McDowall and Eldon (1980), and Rowe and Kelly (2009) changes in morphology of whitebait was also found during the whitebait season, with peaks in inanga total length in October (North Island) followed by a decrease in November, and on Westland rivers a peak in mid-October followed by a decrease in late November. This pattern also occurred for koaro in my study, but only in Westland rivers.

The timing of the decrease in total length varied in different parts of the country and appeared to be effected by a latitudinal gradient. The decrease in mean total lengths occurred earlier in rivers at lower latitudes (upper North Island rivers) compared to those at higher latitudes (South Island rivers). This is consistent with the findings of Rowe and Kelly (2009) where there was a decrease in inanga length on the Mokau River (North Island) two weeks earlier than the Hokitika River (South Island). Again, the effects of ocean temperature experienced by larvae in these different rivers and regions may be influencing the growth of these fish (Schiel, 2004).

The total lengths of koaro varied greatly throughout the sampling period. On the Waiatoto and Cascade Rivers, koaro showed the pattern seen in the whitebait species where fish increased in size and then declined, but a different pattern was seen in Southland and Buller rivers where there was a greater increase followed by a rapid decrease. These differences may be linked with the large fluctuations in the composition of samples.

Temporal variability in the mean total length of koaro may suggest greater dispersal of koaro than other species with fish developing in a number of different locations and achieving different growth due to the water temperature and food supply they have experienced. The widespread distribution of koaro (NIWA, 2015) and associated variation in water temperature of adult habitats may result in the variable onset of spawning (Bruno David, Freshwater Ecologist Waikato Regional Council, *pers. comm.*). For example, koaro living in lakes experience very different water temperatures to koaro living in rivers and streams. Spawning in warmer lakes may occur much earlier than in cooler rivers resulting in variable times of hatching and migration to the marine environment. Oceanic conditions, including water temperature, affect the growth and survival of larvae (O'Connor et al., 2007). For example, if larvae enter the marine environment in February in Bay of Plenty they would be subject to sea surface temperatures of about 21°C, while in August sea surface temperature would be about 14°C (Fig. 3.1;Stevens & Chiswell, 2006).

Alternatively, some larvae may not reach the open ocean and instead complete their development in estuaries or coastal embayments. Again, this would expose developing larvae to different temperatures and food supplies and therefore growth. This was seen with giant kokopu in the Taieri River (Otago) where chemical analysis of otoliths suggested local development in coastal lakes rather than marine dispersal (David et al., 2004).

On the Whakatane River (Bay of Plenty) there was a significant increase in the total mean length of koaro between two samples collected in the first two weeks of September. Due to the unusually small total length of koaro in the first sample (1 September) one of the small whitebait was tested genetically to confirm that it was a koaro whitebait. Although other koaro in Bay of Plenty rivers (e.g., Kaituna River) were found to be extremely small, koaro from the Whakatane River sample were the smallest. These fish may have originated in warmer northern waters (e.g., Hauraki Gulf or Whangerei) and been dispersed into Bay of Plenty by the East Cape Current.

There were significant temporal differences in the condition of whitebait samples. The condition of inanga whitebait was initially low in many rivers and increased throughout the central part of the whitebait season before decreasing again towards the end. The decrease at the end of the season may be the result of late hatching larvae (winter) entering the marine environment with cooler and less productive waters.

In Saltwater Creek and the Waimakariri River (Canterbury) condition increased throughout the sampling period before there was a large decrease on both rivers in mid-November. This may have been due an influx of whitebait that have dispersed from other regions before entering these Canterbury streams.

On many rivers in different regions around New Zealand, inanga, koaro and banded kokopu appeared to follow the same pattern in condition within rivers. For example, on the Waikato River there was a large concurrent peak in condition of all the species at the end of September and on the Rangitikei River a shared peak from September to November. The consistency of variations in the condition of fish across all species suggests these whitebait have developed in the same water mass, or in water masses with very similar characteristics.

4.4.2 Variation between years

While inanga comprised the highest proportion of whitebait samples on all but one river, some rivers had high proportions on non-inanga species at certain times of the year. The largest variation between years was seen on these rivers.

Some of the change could be accounted for by daily fluctuations in species composition as observed by McDowall & Eldon (1980). The earlier timing of migration of banded kokopu on the Kaituna River (Bay of Plenty), and of koaro on the Waiau River (Southland) may be due to earlier spawning of these species due to variability in the timing of elevated flows or temperature cues for spawning.

On the Waikato River there were higher proportions of banded kokopu in 2015 than in 2016, and the Waiatoto River (Westland) had fewer koaro in 2016 compared to 2015. The only statistically significant differences in inter-annual composition were seen on the Waiatoto River and this may have been due to sampling inconsistencies. The sample sizes from the Waiatoto River in 2016 (median = 109 whitebait) were much smaller than those in 2015 (median = 202). On the other hand, banded kokopu and koaro may be selecting different rivers to migrate into depending on a large range of oceanic conditions and weather patterns affecting their dispersal and where they end up when ready to migrate. The slightly higher proportions of koaro in the Waiau River (Southland) may have meant that the Southland Current dispersed fish from South Westland to Southland (Ross, 2009).

4.4.3 Variation over 50 years

I hypothesised that whitebait samples would consist of higher proportions of inanga in 2015 than were found 50 years ago as inanga are habitat generalists that have been found to tolerate lower water quality typical of changes in land use (Boubée et al., 1997; Glova, 2003). In fact, the opposite occurred with higher proportions of koaro and kokopu species being recorded in 2015 samples from the North Island, and the east and west coasts of the South Island.

Throughout New Zealand, modifications to catchments through changed land-use have been extensive in the past 50 years. Intensification of dairying and thus degradation has effected lowland areas at a higher rate than upland areas (Baskaran et al., 2009). Adult inanga inhabit these lowland areas and may have been affected by this degradation more than the adults of other whitebait species. Furthermore, conservation managed areas are concentrated in mainly highland areas and as long as koaro and banded kokopu, which have good climbing abilities, can get past barriers they can get to these adult habitats.

Landlocked populations are known to exist for all five whitebait species. While dams and barriers prevent movement of adults in catchments and the upstream passage of whitebait, larvae spawned in the freshwater may still wash through floodgates and dams. For example, there are large landlocked populations of adult giant kokopu in the Waikato River system, but the Waikato River was found to have the highest proportion of giant kokopu whitebait. These fish may have recruited from other rivers, but may have recruited from the Waikato River.

There were several difficulties associated with comparing McDowall's (1965) historical data with my 2015 samples. Although all the criteria used by McDowall (1965) were followed to determine the species composition across New Zealand some bias may have been introduced. Earlier in this chapter it was shown that species composition changes temporally throughout New Zealand. The exact dates that whitebait samples were collected in 1964 were not known thus there may have been a higher number of samples in a particular area collected at a time when more non-inanga species were migrating. Furthermore, McDowall (1965) included all whitebait samples with >9 fish. In our sampling, because Rowe et al. (1992) found a marked difference in species composition with <100 fish, many samples with smaller sample sizes were not included in further analysis. In Appendix 3.1 I showed that using larger sample sizes increases the chances of non-inanga species being present in samples.

My comparison of whitebait samples from the same rivers in 2015 and 2016 showed that species composition can vary slightly from year to year so inter-annual variation may have played a part in the perceived differences between 1964 and 2015.

Some of the variability in species composition between the 1981-1983 (Rowe et al.; 1992) and 2015 whitebait samples could be attributed to the limited number of samples obtained in 2015 from the Rangitaiki and Whangaparoa Rivers, the time during the season these samples were collected, differences in methods used to catch whitebait, or that fish were only collected over a single year on three of the four rivers in 2015 compared to three years in the 1980's study.

The Kaituna River (Bay of Plenty) was sampled extensively in 2015 and 2016, and there appeared to be a shift in species composition from that seen in the 1980's with higher proportions of banded kokopu being found in whitebait samples and fewer koaro. Koaro populations are highly susceptible to predation from trout and competition from smelt. These pressures have caused large declines in koaro populations in the North Island (Rowe, 1993; Rowe et al., 2002). Trout have been observed in artificial wetlands created on the banks of the Kaituna River (Peter Ellery, *pers comm*), and the lack of avoidance of migrating galaxiids to introduced predators such as trout could further account for this change (McLean, 2007). Many rivers sampled in Bay of Plenty had low proportions of koaro suggesting a regional decline in koaro populations from 30 years ago.

On the Whakatane River there were lower proportions of banded kokopu and koaro in 2015 than during the early 1980s. Although tributaries of the Whakatane River drain extensive bush covered catchments suitable for adult koaro and banded kokopu (McDowall, 2000; Baker & Smith, 2007; Britton, 2008), altered water quality and flows (Boubée et al., 1997; Elosegi, 2013) may have influenced the ability of kokopu species to complete their diadromous life cycle and affected recruitment. For example, increased urbanisation and intensification of dairying in the Whakatane catchment have likely further reduced water quality (Dudgeon et al., 2006) and the construction of flood defences in the catchment from 1965 to the 1980's (Britton, 2008) may have increased velocity and suspended sediments reducing the ability of whitebait to migrate to upstream adult habitat (Elosegi, 2013).

A comparison of the lengths of inanga in samples from the Waiatoto River (Westland) in 1969-1972 with 2015-2016 showed some variability in size but a similar overall pattern across years. As described by McDowall and Eldon (1980), it is evident that each year there are consistent relationships between species sizes. There were day-to-day fluctuations in the length of migrating whitebait, but an overall increases in length in early September followed by a peak in early October and a decrease in length in early November. McDowall and Eldon (1980) found that these peaks in length coincided with peak migrations of whitebait. This variability could be explained by the variable timing of spawning of inanga from year to year, and the sea temperatures experienced by larvae in the marine environment that affect growth (Schiel, 2004).

CHAPTER FIVE: GENERAL DISCUSSION

5.1 Overview

Multiple factors interact to shape the diversity and weight of whitebait in a whitebaiter's bucket. These factors include where in the country they are fishing, the date they are fishing, the type of net they are using, how far they are fishing from the river mouth, whether the river has a forested catchment, whether adult whitebait are present in the catchment, whether it has rained heavily in the last few days, and a mix of skill and luck.

This thesis investigated spatial and temporal variations in the species composition and morphology of New Zealand's whitebait fishery. It described intra- and inter-regional differences in the whitebait catch and changes over annual, biannual and 50 year periods. It provided a New Zealand-wide overview of the fishery, including regional differences in the timing of whitebait migrations, further indications of the extent of dispersal and knowledge for future reviews of the management of the fishery and conservation of whitebait species.

5.2 Species composition and what affects it

This is the first study that has been able to get a simultaneous view of the species composition of the whitebait fishery around New Zealand, including Southland, Manawatu-Wanganui and Bay of Plenty. Nationally, the fishery consisted of high proportions of inanga and lower, and more variable, proportions of non-inanga species. Koaro and banded kokopu whitebait were found in high proportions in some rivers and at certain times of the year, but giant kokopu and shortjaw kokopu whitebait were rare and patchily distributed throughout the 6 month sampling period. These patterns are very similar to those described by McDowall (1965), McDowall and Eldon (1980) and Rowe et al. (1992).

Some of the regional variability in species composition is probably due to ocean currents. Oceanography also provides evidence for regional dispersal but distinct populations of whitebait. Fish originating in Southland and Otago have the ability to disperse northwards with the Southland current. Fish from Manawatu-Wanganui and Tasman-Nelson have the ability to disperse through Cook Strait with the D' Urville current. While fish in the Waikato are likely retained on the West Coast of the North Island under the influence of the Tasman Current and West Auckland Current, fish from the Coromandel and Bay of Plenty are likely to be retained in the Bay of Plenty with the East Cape Eddie and fish from Hawkes Bay retained in the Wairarapa

Eddie (Schiel, 2004; Ross, 2009; Chiswell & Rickard, 2011). Studies show evidence of both extensive dispersal such as McDowall et al. (1975) where galaxiid larvae 3 months old have been found 700km from the New Zealand mainland, as well as localised dispersal in giant kokopu (David et al., 2004). Due to oceanography there are, however, some locations where fish could not disperse. For example, whitebait originating in Waikato of Bay or Plenty are highly unlikely to reach the West Coast as currents do not allow it. Likewise, fish originating in Buller are highly unlikely to disperse to Canterbury. Therefore, variability in ocean currents combined with the variability in morphology seen in this study and evidence from other studies such as Hickford and Schiel (2016) indicates strong evidence for different whitebait populations in New Zealand despite regional mixing.

More localised variability seen among species within regions gives further evidence that whitebait select rivers based on chemical information dispersed within the water column. This study showed there was an association of high proportions of koaro and kokopu species migration into rivers with high forest cover. Therefore, koaro and kokopu species are probably selecting rivers based on these factors. However, while Rowe et al. (1992) also found that migrating koaro may select rivers this did not relate to environmental variables. On the other hand, Baker and Montgomery (2001) and Baker and Hicks (2003) found that banded kokopu and koaro juveniles responded to pheromones of adults indicating river selection based on adults in catchments. In their experimental trials koaro and banded kokopu had species-specific attraction to adult pheromones, while inanga responded to all adult whitebait species pheromones. This could also be the reason why inanga are also found in relatively pristine catchments. River selection occurs for other diadromous species such as glass eels that appear to sense odours from freshwater microbes (Tosi & Sola, 1993) and lampreys that sense odours from upstream larval fish (Baker & Hicks, 2003; Fine et al., 2004).

Variation in river types and associated water quality may also be important in river selection. In this study banded kokopu were found in higher proportions in smaller pristine streams in comparison to high proportions of koaro that were found in larger glacier-fed rivers. Some of this variation may be due to temperature but also with these species tolerances to suspended sediments. Glacier-fed rivers are cooler and often have higher sediment levels and smaller more stable streams are warmer with less sediment (Boubée et al., 1997). This is consistent with findings from McDowall and Eldon (1980) who also found that koaro travelled into cooler glacier-fed streams while banded kokopu entered warmer, slower, stable streams.

However, this may also relate to the distance that species disperse. Whitebait can sense freshwater plumes, which guide them back to return to rivers and streams (Hickford & Schiel, 2011) (Fig. 5.1). During flood events these plumes can reach many kilometres out to sea and large proportions of koaro have been found to run shorewards after such events. The results of McDowall and Eldon (1980) correspond with this study where high proportions of koaro were found in larger river systems such as the Buller and Waiatoto Rivers (West Coast). This suggests that koaro may disperse several kilometres offshore. On the other hand, banded kokopu are found to comprise high proportions of samples on smaller rivers with smaller freshwater plumes, suggesting banded kokopu may stay closer inshore.

Figure 5.1. Freshwater plumes from the Waimakariri River (Canterbury) penetrate several kilometres out to sea. Migrating whitebait that sense this plume use them to navigate back to freshwater (Stevens & Chiswell, 2006).

Land use practices can greatly influence variability in species composition. rarer kokopu species were found in unmodified environments, in comparison to mainly inanga in highly modified environments. In regions such as Canterbury and Hawkes Bay, which have been subject to a vast increases in dairying in recent decades, species composition comprised >95% inanga. On the other hand, partially or unmodified systems had higher proportions of non-inanga species than these modified systems. Inanga are habitat generalists with juveniles tolerating high levels of sedimentation and elevated temperatures in comparison to other whitebait species (Boubée et al., 1997; Glova, 2003). This is important because regionally there are few populations of non-inanga species, particularly shortjaw kokopu, which indicates they would be highly susceptible to modification. For example, deforestation or intensive modification in Buller, which had high proportions of non-inanga species in whitebait samples, could have resulted in a total collapse of the fishery. Furthermore, continued degradation of already modified systems such as Canterbury could also lead to a collapse of the fishery. The lack of suitable inanga spawning habitat results in fewer eggs and a lower condition of fish (Hill, 2013), reducing numbers of whitebait originating from these rivers. This coupled with the fact inanga are an annual species suggests populations are vulnerable to sudden or serious declines from multiple stressors (McDowall & Eldon, 1980). This was found in a similar fishery, the Tasmanian *Lovettia* whitebait fishery, where once highly abundant catches declined rapidly with increased fishery pressure over 8 years for this annual species (Blackburn, 1950; McDowall & Eldon, 1980).

5.3 Morphology and what affects it

Part of this variability is related to morphological differences in fish around the country. Are these true differences in morphology or are they simply allometric effects with bigger fish in some regions and smaller fish in others. Regions that stood out as being most different were Bay of Plenty and Buller. Whitebait in the Bay of Plenty were vastly different to whitebait in Buller in terms of length, body depth and condition. Buller fish were longer, had a greater width and were in better condition. These differences seemed to apply to all species in the same way for most criteria.

There are many reasons why Bay of Plenty whitebait may be different. These include differences in growth rates, tissue development, feeding, metabolism, predation pressure, behaviour, swimming speed and migration (Blaxter, 1991; Farrell, 2009; Garrido et al., 2016) which can then be affected by seasons, wind, currents, food availability and temperature --- all of which may affect fish physiologically (Jennings et al., 2009). Eimear Egan (current PhD, in progress) has been examining these issues. She also found considerable variation in inanga morphology and growth. Inanga from Bay of Plenty grew faster and dispersed less than fish in Canterbury. Therefore, differences in morphology may be partially due to being younger, developing more quickly, spending less time in the plankton and migrating earlier. While all of these affect morphology, and it is difficult to know which are more important, the fact remains that their morphology is different.

Not only were there difference in morphology within species but there are differences in the species themselves. Whitebait species were found to have different length/weight relationships, which were consistent in different parts of the country. Banded kokopu were always smaller than inanga. The large body size of inanga may increase the ability of inanga to reach sexual maturity at 1 year of age and, because they occupy lowland areas, there is little benefit in being a good climber and therefore having a smaller body size. On the other hand, banded kokopu reach sexual maturity at 2-3years and have plenty of time to grow, but their small body size aids in their excellent climbing ability to reach adult habitats that can be large distances upstream. These differences also relate to other variability seen within the species' life histories characteristics (as discussed in section 2.1).

Other closely related species show variation in morphology and other characteristics. Salmonids differ in morphology, as well as in breeding seasons, fecundity, age to reach sexual maturity and degree of anadromy (Willson, 1997). Morphology differences include body proportions, fin size, and jaw characteristics both among species populations with differences associated in foraging and habitat and also probable concomitant differences in ecology (Willson, 1997). Similarly, bullies (*Gobiomorphus* sp.) show variation in morphology, and characteristics (McDowall, 2000). For example, giant bullies (*G. gobioides*) often reach 150 mm and are stout with big fins whereas bluegill bullies (*G. hubbsi*) are often only 50-60mm in length and have a shorter body depth in comparison to their length (McDowall, 2000).

5.4 Important discoveries and areas for future research

Several discoveries from my research help resolve many questions. However, there are areas that still need resolution, some of which can be at least partially resolved from my large data set; others will require different types of research.

A parallel study by Egan is assessing otolith structure to understand age-related effects of migration and larval growth in inanga. Her study will provide knowledge on internal cues as to why species vary, and answer related questions about the marine life phase. Furthermore, using my data set, another student is examining age and growth of the four non-inanga species. This is important as not only are koaro and banded kokopu also important to the fishery in some rivers and regions but the rarer giant kokopu and shortjaw kokopu have never been identified from many of these rivers and we know little about them.

Within this data set the population structure of species will be examined. This will be useful to understand more about the genetics of the population structure of other species, as current knowledge indicates there are clearly leaky borders in marine pools of whitebait and at least some movement between regions.

Discoveries from my work include understanding the species composition in many regions previously not known, especially relating to some of the first discoveries of giant kokopu and shortjaw kokopu in many rivers around the country. In particular, understanding the timing of migration of these species, and where and when they are likely to be found, gives some predictive power in helping to target particular species for future work. For example, there is a strong association of shortjaw kokopu with adult populations and forest cover in relatively pristine streams which a known migration period of October and November. There are limitation such as whether these patterns occur each year, and the fact there were only few observations, but this knowledge may help target this future research. There is potential to undertake an extensive targeted survey of giant kokopu and shortjaw kokopu in targetted regions to gain a better understanding of the timing of migration. Still, it is difficult to work on rare species and working on them is often a marginal exercise.

My study indicates that non-inanga species are probably the ones most affected by land use change, especially giant kokopu and shortjaw kokopu. There is a growing number of stream rehabilitation projects attempting to fix degradation problems. However, there is little knowledge of whether these projects have been successful in increasing fish production (Cockerill & Anderson, 2014). There are many shortcomings in these projects including targeting habitat that is highly degraded with limited ability to restore ecosystem functioning, the lack of maintenance of riparian planting, failure to restore connectivity and underlying problems that caused the degradation in the first place (Roni et al., 2008). There is huge potential to study the long term successes or failures of stream restoration and rehabilitation projects and have more targeted approaches. These rare species in particular should be monitored to see whether rehabilitation projects have affected them. In the knowledge that non-inanga species may be selecting rivers there is also the potential to trial more fish introductions into these partially degraded systems to aid in conservation. What is clear in New Zealand conservation is that through dedicated research and innovation, trial and error, and the development of improved and new technology, the seemingly impossible can become common place.

This study has provided further insight with the into the oceanic life phase of whitebait and potential dispersal with widespread information on the morphology of the five whitebait species. This coupled with studies by Dr. Gerry Closs and his students gives further evidence for understanding of whitebait dispersal.

External to this study, it is important to understand the survivorship at the different life stages of these fish. Currently it is not known how many whitebait get past the nets of whitebaiters, and once in the river how many fish reach adulthood. Modelling these factors may allow areas of their life stages that may be limiting recruitment to be identified, and strategies can be employed in fisheries management and conservation that have the biggest impact on maintaining whitebait species populations. For example, the removal of riparian margins resulting in the loss of a few adult shortjaw kokopu in a catchment that have the potential to produce thousands of eggs would likely have a much greater impact than catching a few hundred shortjaw kokopu whitebait in a whitebaiters net. Shortjaw kokopu adult populations are rare and patchily distributed thus removing these fish may result in a total regional loss of these species. Thus, efforts may be better targeted at identifying these populations and protection of these areas rather than focusing too much on preventing these species from getting past the whitebaiter net.

Furthermore, continued research is needed to understand the basic biology of adult whitebait species. An extensive review of the literature revealed many gaps in basic biology of whitebait species and facts are based on single observations. For example, spawning of koaro has only been documented once (Allibone & Caskey, 2000) and it is not known if this is representative of spawning koaro in other rivers in other parts of the country.

5.5 Implications for Management

I close this thesis with management implications because it was one of the main reasons for this study. This study showed large differences in the species composition and morphology of the whitebait fishery both spatially and temporally between and within regions. It gives weight to the existence of regional populations, provides support for targeted regional management and will inform any future review of the whitebait fishery. Such a review might include new restrictions on the timing of the open season to allow unimpeded passage of particular species, the introduction of more closed rivers in other parts of the country, targeted management, and solutions to the constraints of the current management of the fishery.

There is currently considerable controversy surrounding the whitebait fishery: how it is currently managed, the levels of compliance, the rules in place, how they are interpreted, questions about the 'commercial' fishery and the lack of catch restrictions, the ability to sell whitebait, the impact of whitebaiting on fish populations, the sustainability of the fishery, and the overall conservation of whitebait species. I will briefly address some of these issues in the next section.

5.5.1 Spatial management of some aspects of the fishery

The whitebait fishery has changed considerably and evolved over the decades from 1894 when the first regulations were introduced (McDowall, 1984b). Past regulations from the early 1900,s were complex and involved diverse characteristics to account for local differences (McDowall, 1984b). From 1932 onwards there has been a move towards greater simplicity and national conformity (McDowall, 1996b).

The West Coast whitebait fishery is managed separately from the rest of New Zealand with additional rules such as a reduced fishing season, back markers (a limited distance upstream from the mouth that can be fished) and closed rivers (West Coast Fishing Regulations 1994 – www.doc.govt.nz/coastwhitebait). For decades, the West Coast whitebait fishery has had special provisions because it was thought to be distinctive and highly productive. However, managers can only make decisions based on available data and some bias may have been introduced because of the concentrated research fishing efforts on the West Coast compared to other regions.

My study showed that other important whitebaiting regions are as diverse and distinctive in the species composition and morphology of whitebait as the West Coast. In particular, we now know that Tasman-Nelson, Wellington and Waikato also have high proportions of non-inanga species including giant kokopu and shortjaw kokopu. Although intensive regional studies need to be completed to understand the full extent of the species composition of shortjaw kokopu migrations, we now have a comprehensive overview of the species composition of the whitebait fishery and spatial and temporal changes throughout New Zealand.

In 1994, the West Coast whitebait fishery was shortened by two weeks for conservation of the later-migrating giant kokopu. Although the closure of the West Coast whitebait season was eventually shifted to 15 November, the initial proposal reduced the season even further. A critical review by the Department of Conservation in performance and management of the whitebait fishery included the proposed curtailment of the fishery to 31 October to allow even greater protection of migrating giant kokopu from whitebaiting. However, after an appeal by the West Coast Whitebaiters Association to the Regulations Review Committee of Parliament the date changes were revoked and the Department of Conservation restored the closure of whitebait fishing season to 15 November (McDowall, 1996b).

If fisheries managers want to allow for greater escapement of giant kokopu and shortjaw kokopu whitebait then the timing of the season could be altered on the West Coast and possibly other regions. For example, in West Coast rivers, giant kokopu and shortjaw kokopu whitebait were found in early November when whitebaiting is still allowed, so shortening the season may aid them. In the North Island, giant kokopu and shortjaw kokopu whitebait were found to enter rivers much earlier (October) and during the current whitebaiting season.

It is not known why the West Coast fishery is reduced by two weeks at the start of season (start date Sept 1) compared to the rest of New Zealand (Aug 15). My own and past studies have shown that inanga are the primary whitebait species entering West Coast rivers in with very low (<12%) proportions of koaro whitebait in only some rivers. The West Coast whitebait fishery could start and finish two weeks earlier (15 August to 31 October) than currently to allow unimpeded passage for peak migrations of giant kokopu and shortjaw kokopu whitebait and reduce the number of post-juvenile fish (mainly resident inanga) being caught.

In the North Island, my study is the first to detail the timing of giant kokopu whitebait migrations: which are mainly during on west coast during October and November. Given the earlier migration of giant kokopu in the North Island, together with the fact that very few whitebait are caught during November in northern rivers, consideration could be given to finishing the North Island whitebait season earlier. Furthermore, in the North Island in November there is significant bycatch of 'gutty fish' (post-juvenile and adult inanga). This has been observed for many years by whitebaiters and Department of Conservation rangers with mainly sub-adult fish being caught from November (Chris Annandale, Department of Conservation Ranger, *pers. Comm.*). For example, on the Waikato River only a few fresh run whitebait were found among several kilograms of post-juvenile and adult inanga in samples from November and December (Fig. 5.2). These 'gutty fish' are left dead, or damaged or are discarded after being sorted by whitebaiters to find the few fresh-run whitebait.

Figure 5.2. Whitebait sample from the Waikato River from November showing the large number of post-juvenile and adult inanga that are caught as 'whitebait'.

While collecting samples for this study, I received a lot of feedback from whitebaiters over the ability of whitebaiters to fish without limits and to sell their catch. There is increasing support for a catch limit or/quota system to be introduced. Knowledge from my study of the variability in the morphology of whitebait will be vital to developing such a system. For example, quota systems are usually based on tonnage and my study identified large temporal and spatial differences in the weight of whitebait as discussed in Section 3.4.2. Similarly, there are large differences in weight between the different species. This, combined with regional variability in species composition, results in very different numbers of fish being caught in a kilogram of whitebait in different regions. For example, in October in Canterbury rivers, whitebait species composition consisted of 99.9% inanga and 0.1% koaro resulting in a total of 2856 fish per kilogram (2854 inanga, 2 koaro), but in October in Buller rivers, composition consisted of 21.7% inanga, 22.8% koaro, 55.4 % banded kokopu and 0.1% giant kokopu. This results in a total of 2310 fish making up a kilogram of whitebait (443 inanga, 335 koaro, 1530 banded kokopu and 2 giant kokopu).

Interestingly, region–specific rules and catch limits are very common in New Zealand's marine recreational fisheries. For example, the recreational snapper (*Pagrus auratus*) fishery in Northland, Waikato and the Bay of Plenty (Auckland and Kermadec area) has a daily bag limit of 7 fish with a minimum fish length of 30cm, but in Canterbury (South-east area) limits include 10 snapper with a minimum size of 25cm (MPI fishing regulations, www.mpi.govt.nz/travel-and-recreation/fishing/fishing-rules).

5.5.2 Freshwater reserves/closed rivers & integrated management

The West Coast of the South Island has approximately 18 rivers that are permanently closed to whitebait fishing. Some of these have been closed for five decades (e.g., Mahinapua Creek was closed in 1964), but many others were closed by the Department of Conservation in 1994 regulations (McDowall, 1996b, 1999). These closed rivers are generally located on the tidal reaches of West Coast rivers as precautionary conservation measures to ensure sufficient escapement of whitebait or to protect important spawning grounds (McDowall, 1999).

In terms of protecting the more threatened of the whitebait species, there is potential to close rivers to whitebaiting in regions other than the West Coast. As with Rowe et al. (1992), I found a positive association between the level of forestation of a river's catchment and the abundance of koaro and kokopu whitebait entering that river. High proportions of koaro, banded kokopu, giant kokopu and shortjaw kokopu entered and streams with a high proportion of forest cover in their catchment. Catchment forest cover also has a positive correlation with the abundance of adult koaro and kokopu species (Main, 1988; Goodman, 2002; NIWA, 2015).

Targeting several pristine catchments in different regions for whitebaiting closure would allow more widespread escapement (beyond the West Coast) of non-inanga whitebait. If combined with habitat protection or restoration, these closed rivers could act as sources of larvae for regional larval pools (Hickford & Schiel 2011; Hickford & Schiel 2016). For example, the Waikawau River (Waitomo District, Waikato) has largely intact forested headwaters that drain through lowland farmland to the sea. Inanga made up the highest proportion of species in samples, but koaro, banded kokopu, giant kokopu whitebait were found migrating into this catchment and adult shortjaw kokopu are found in the headwaters, suggesting they must also migrate into this river despite not being detected in this survey. Protection of this and similar catchments from fishing pressure as well as protecting or enhancing spawning and adult habitat could improve regional productivity of both inanga and non-inanga whitebait species.

This idea could also provide opportunities for targeted integrated management so stream rehabilitation projects could get the greatest gain from limited resources. There are currently many rehabilitation projects in New Zealand with a focus on riparian planting, but without targeted goals (Cockerill & Anderson, 2014; Peters et al., 2015). While these projects may improve water quality, there has been no evidence that they improve invertebrate or fish production or diversity (Cockerill & Anderson, 2014). Integrating these rehabilitation projects with whitebaiting closures may prove to add considerable valueto aiding whitebait populations.

The current management of the whitebait fishery targets only one small piece of the puzzle (harvesting) rather than targeting the conservation of diadromous galaxiid species and the sustainability of the fishery. Whitebaiting must have some impact on fish populations, but there is a complex web of impacts including changes to landscapes, vegetation and water quality that also affect fish populations and that cannot be disentangled from the possibility of overharvesting (McDowall, 1996b). Therefore, integrated approaches (including habitat protection, education and continued research, in addition to improved controls on the fishery and compliance) need to be used to ensure the whitebait fishery is sustainable.

The peak condition of fish in my study coincided with peak migrations when whitebaiters catch large amounts of whitebait (McDowall & Eldon, 1980). Whitebait in better condition not only have better reproductive potential (i.e., they produce more eggs; (Hill, 2013), but they may also have a better chance of surviving to adulthood. Instead of closing the entire fishery to whitebaiting during the middle of the season, a network of closed rivers would give at least some of these peak condition fish in each region the opportunity to reach sexual maturity.

A nationwide network of rivers closed for whitebaiting would require targeting and clear criteria to ensure its effectiveness. For example, important characteristics would include the presence of natural habitats, adequate size, permanent water supply, the absence of exotic fish species and access to and from the sea (McDowall, 1984a). Some areas could be targeted for important spawning areas while other for the presence of rare species in the catchment. Additionally, there may be more benefit in rehabilitation of rivers and streams with several threats to existing populations than trying to build populations that have already been lost.

The Wainui River (Tasman-Nelson) is an example of an ideal river to close for whitebaiting. Its headwaters are partially located within the Able Tasman National Park and it drains extensive indigenous forest before flowing through farmland into Wainui Bay. The adult and spawning habitat of whitebait species appears intact, there is permanent water with unrestricted access to the sea, NZ Freshwater Fish Database records show the presence of four of the five whitebait species in this catchment and there is potential for rehabilitation such as fencing, riparian planting and enhancement of spawning areas.

My study clearly showed that inanga make up the highest proportion of the whitebait fishery so targeted conservation of inanga is more important than non-inanga species for fishery sustainability.

The Styx River (Canterbury) may be a good stream to target for inanga conservation through closure to whitebaiting and integrated management. This small stream flows into the Waimakariri River which has an extensive wetland area with existing inanga spawning habitat (Taylor & Bradshaw, 2005). Flood gates in the lower Styx River currently impede the upstream passage of whitebait, but these gates could be made fish passage friendly and adult habitat in the upper catchment enhanced. Furthermore, this concept is already supported by many local whitebaiters that fish the Waimakariri River (*Fiona McKenzie, pers. comm.*).

In New Zealand, there are many large, flood-prone river systems that require flood control defences such as channel straightening, armouring and the construction of stopbanks (Harding et al., 2004). Many of these rivers are also important whitebaiting rivers (e.g.,Rangitaikei River (Bay of Plenty), Ngaruroro River (Hawkes Bay), Manawatu River (Manawatu-Wanganui), Buller River (Westland), and Waimakariri River (Canterbury). Often as well as the modifications to the mainstem, tributaries and floodplains that are often highly degraded from farming practices have been infilled or have lost connectivity with the main river (Allan, 2004). These tributaries and their confluence with the mainstem are often important spawning habitats for whitebait species (Taylor 2002). In this study, whitebait samples from many of these larger rivers were comprised of >95% inanga. Furthermore, Hickford and Schiel (2011) found sink populations in catchments like the Buller River where no suitable inanga spawning habitat exists. There is huge potential for restoration of these floodplains to provide much needed habitat for these maturing and spawning. For example, on the Kaituna River (Bay of Plenty) the construction of artificial wetlands have been trialled and were found to be provide important inanga rearing habitat and were found to be a highly productive spawning areas (Ellery & Hicks, 2009; Ellery, 2016). Many highly modified rivers have large numbers of inanga migrating into them with little or no spawning areas, thus rehabilitating these areas to be productive spawning grounds would be highly beneficial to the inanga populations and the whitebait fishery.

5.5.3 Management of the fishery through the Department of Conservation.

There is still some concern about the Department of Conservation's ability to manage the whitebait fishery (McDowall, 1996b). The Department of Conservation is subject to an environment where decreasing resources and funding shared among a growing range of projects (McDowall, 1996b). This has caused a shift from whitebait research and management (McDowall et al., 1996). It has also been suggested that there is conflict with the Department of Conservation's responsibilities to conserve freshwater fish species as well to manage their exploitation through the whitebait fishery (McDowall, 1996b).

The issues surrounding the management of the whitebait fishery are complex, but there are alternative structures that could be considered. The Department of Conservation has the ability to work within freshwater, marine and terrestrial environments and to integrate fish conservation across them, therefore it is best that the conservation of whitebait species and continued education/community engagement should remain with them. Management of the whitebait fishery and enforcing of compliance with the regulations could be taken over by another entity. Whether this is the Ministry of Primary Industries, who currently control all marine fisheries, or another entity could be debated.

Limitations on resources to manage the whitebait fishery and enforce compliance with regulations could be overcome with the introduction of a whitebaiting licence. A licence for recreational whitebaiters would provide the necessary funds for more-frequent compliance enforcement and research to manage the fishery sustainably. For example, in New South Wales recreational fishers are required to purchase a fishing licence (3 day, 1 month or 1 year) from the Department of Primary Industries for a small fee (AUD$7-85). This licence allows the holder to fish in freshwater and saltwater environments with the fees going to a trust tasked with improving recreational fishing (http://www.dpi.nsw.gov.au/fishing/recreational/recreational-fishing-fee). Likewise, Fish and Game NZ manage, maintain and enhance sport fisheries in New Zealand with anglers required to have a licence (1-day or season) with fees (NZ$20-125) funding conservation of rivers, restocking sport fish, and compliance. A major additional benefit of such a whitebaiting licence would be the ability to gather valuable information during the application process such as the number of people whitebaiting in specific rivers and regions.

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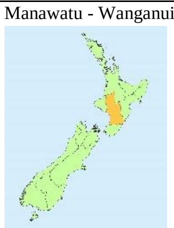
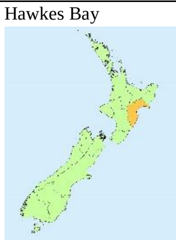
APPENDIX ONE: CHARACTERISTICS OF RIVERS SAMPLED IN 2015

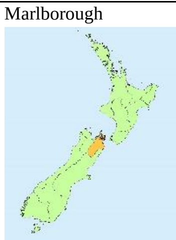
Table A1.1. Characteristics and locations of 92 rivers sampled during the 2015 study.

Region	River	River Number	Coordinates NZTM (Northing)	Coordinates NZTM (Easting)	Catchment Area (km2)	Indigenous Forest Cover %	Pasture Cover %	Pictures of River and Site	
Auckland 	Hoteo River	1	5968724	1731924	35782	12	64		
Waikato 	Waikato River	2a	5870698	1763215	1448210	13	54		
		2b	5869992	1762606	1448210	13	54		
		2c	5861434	1751557	1448210	13	54		
	Waingaro River	3	5820865	1772612	12288	14	76		
	Oparau River	4	5786878	1769039	11988	35	61		
	Marokopa River	5	5759434	1750136	36440	43	49		
	Waikawau River	6	5739923	1743952	8203	75	18		
	Awakino River	7a	5720057	1743232	38301	48	47		
		7b	5719142	1743184	38301	48	47		
	Mokau River	8a	5714125	1743233	144507	25	69		

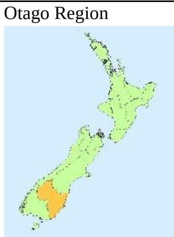
	Mokau River	8b	5714343	1744772	144507	25	69		
Taranaki 	Onearo River	9	5682031	1718465	8866	40	52		
	Waitara River	10	5683189	1706657	113954	34	59		
	Waingongoro River	11	5617820	1702787	23303	5	93		
Manawatu - Wanganui 	Kai Iwi Stream	12	5583327	1762290	19130	1	65		
	Whangaehu River	13	5565439	1779286	199221	10	62		
	Rangitikei River	14a	5536050	1789089	392983	12	58		
		14b	5537798	1790022	392983	12	58		
	Manawatu River	15	5517422	1787969	587830	6	79		
	Owahanga River	16	5496615	1882030	40814	0	96		
Wellington 	Otaki River	17	5485570	1779194	34972	78	10		
	Peka Peka Stream	18	5478578	1773787	Unknown	0	96		

	Waikanae River	19	5473524	1769092	15328	35	33		
	Pauahatanui Stream	20	5447860	1760689	4168	1	58		
	Hutt River	21	5434624	1759302	63806	42	14		
	Ruamahanga River (Lake Ferry)	22	5414914	1779107	336159	22	42		
Coromandel 	Wentworth River	23	5877413	1854088	2527	63	20		
Bay of Plenty 	Tuapiro Creek	24	5846189	1858864	5231	65	30		
	Kaituna River	25	5816295	1899411	119979	25	42		
	Tarawera River	26	5799620	1933140	82089	24	26		
	Rangitaiki River	27a	5797119	1941342	296075	25	17		
		27b	5796897	1941216	296075	25	17		
	Whakatane River	28a	5792341	1952048	24429	10	87		
		28b	5790485	1947926	24429	10	87		

	Nukuhou River	29	5782559	1960587	10282	21	51		
	Otara River	30	5785550	1976166	33095	76	14		
	Waiaua River	31	5786193	1985467	9787	44	47		
	Waiotahi River	32	5785585	1967784	14320	57	23		
	Whangaparaoa River	33	5830263	2042461	17974	39	33		
Hawkes Bay 	Wairoa River	34a	5666823	1982503	367429	34	49		
	Wairoa River	34b	5677848	1981816	367429	34	49		
	Ngaruroro River, Tutaekuri River and Clive River (Mouths)	35	5613244	1937288	337042	11	53		
	Tutaekuri River	36	5613282	1935867	337042	11	53		
	Clive River	37	5609637	1935434	337042	11	53		
	Tukituki River	38	5609232	1938900	250561	8	83		
	Porangahau River	39	5531952	1907031	85551	2	87		
Wairarapa	Whareama River	40	5456740	1858416	53144	3	70		

Tasman - Nelson 	Aorere River	41	5497281	1573085	68483	51	19		
	Parapara River	42	5491381	1573032	3805	83	1		
	Takaka River	43	5480200	1582493	87097	61	13		
	Wainui River	44	5480897	1594994	3141	2	78		
	Motueka River	45	5451733	1601227	205664	35	19		
Marlborough 	Wairau River Diversion	46	5411970	1685671	358264	0	91		
	Wairau River	47	5405256	1688643	358264	0	91		
	Opawa River	48	5404212	1687141	41568	2	68		
	Awatere River	49	5393051	1697239	157683	1	21		
Canterbury 	Hapuku River	50	5313605	1660983	13517	2	13		
	Lyell Creek	51	5305149	1656332	1632	0	91		

	Kowai River	52	5303597	1652118	8403	1	10		
	Saltwater Creek	53	5209989	1576585	9272	0	93		
	Ashley River	54	5209256	1577728	114912	0	98		
	Waimakariri River	55	5195787	1576458	361187	0	8		
	Styx River	56	5195049	1575016	3511	0	8		
	Avon River	57	5181634	1574196	16607	0	55		
	Heathcote River	58	5177740	1573147	11417	0	47		
	Opara Stream	59	5160103	1602938	13387	1	83		
	Le Bons Stream	60	5156440	1607897	2488	0	70		
	Robinsons Stream	61	5154340	1597026	1173	0	86		
	Pawsons Stream	62	5155776	1594477	733	1	83		
	Orari River	63	5100000	1472914	71514	1	23		
	Opihi River	64	5095137	1467978	237619	1	62		
	Waihao River	65	5040696	1455335	55459	0	82		

	Waitaki River	66	5023200	1454004	1190107	Unknown	Unknown		
	Kakanui River	67	4993962	1434925	89658	1	82		
	Shag River	68	4961925	1426118	54482	0	63		
	Taeri River	69a	4896504	1384381	570607	1	51		
Otago Region 	Taeri River	69b	4896504	1384381	570607	1	51		
	Owaka River	70	4851212	1344986	41568	21	64		
	Waikawa River	71	4832555	1303840	20675	43	52		
	Mataura River	72a	4834286	1273221	538803	6	59		
	Mataura River	72b	4834273	1272117	538803	6	59		
	Titiroa River	73a	4836021	1276263	21107	8	84		
	Titiroa River	73b	4835293	1275914	21107	8	84		
	Oreti River	74	4843734	1238469	352151	11	64		

Southland 	Aparima River	75	4858156	1215919	157091	16	58		
	Waiau River	76	4870537	1184130	824768	37	19		
	Oparara River	77	5437327	1525898	13387	92	3		
	Karamea River	78	5432665	1525318	121026	78	1		
	Little Wanganui River	79	5418651	1522308	18217	80	5		
	Mokihinui River	80	5402094	1511913	75114	29	15		
	Orowaiti River	81a	5375953	1486269	4728	31	37		
		81b	5375865	1486333	4728	31	37		
Buller 	Buller River	82a	5375280	1483410	637807	20	79		
		82b	5376181	1483317	637807	20	79		
	Punakaiki River	84	5335144	1462223	6330	100	0		
	Taramakau River	85	5285967	1447303	100503	6	69		
	Waimea Creek	86a	5278437	144897	4160	31	21		

		86b	5280692	1443178	4160	31	21		
	Hokitika River	87a	5267498	1432929	106814	43	12		
		87b	5268060	1433299	106814	43	12		
	Wanganui River	88a	5231797	1391071	52355	36	12		
		88b	5231866	1391895	52355	36	12		
	Okarito River	89	5210827	1369798	30133	62	2		
	Paringa River	90	5162021	1312255	36626	Unknown	Unknown		
Westland 	Waiatoto River	91a	5120398	1263028	53111	42	0		
	Waiatoto River	91b	5120738	1262896	53111	42	0		
	Cascade River	92	5114218	1229641	43701	45	4		

Note: On rivers where multiple samples were taken on different parts of the river coordinates are given for both sites. Note: Although Wentworth River (Coromandel) is part of the Waikato Region, Whareama River (Wairarapa) is part of the greater Wellington Region, and Owahanga River is part of Manawatu-Wanganui they have been separated in analysis due to their positions on different coasts to other regional rivers.

APPENDIX TWO: FIELD SHEET

WHITEBAIT SAMPLING FIELD SHEET

FUNDAMENTALS

RIVER/STREAM.. REGION..

DATE... WHITEBAITER...

START TIME... FINISH TIME...

FISHING INFORMATION

FISHING EQUIPMENT...(Scoop net, set net, fold up net)

EXACT FISHING LOCATION...(describe, GPS, river left or right bank)

FISHING METHOD...(single site, multiple sites, continuous fishing along river bank)

TIME MAJORITY OF FISH WERE CAUGHT...

MAIN SHOAL SIZE (1-4)...(1=5 fish or less, 2=ca.20 fish, 3=ca.50 fish, 4=100 fish or more)

SCHEDULED HIGH TIDE.. TIME TIDE TURNED...(where you were fishing).

WAS THIS A SUBSAMPLE?..(Y/N) IF SO, TOTAL NUMBER OR WEIGHT OF FISH CAUGHT..

HOW MANY OTHER WHITEBAITERS WERE SEEN FISHING?..

WEATHER

CONDITIONS (1-4)...(1=fine/sunny, 2=overcast, 3=mist/fog, 4=rain)

PRECIPITATION (1-4)..(1=none, 2=light,3=moderate, 4=heavy)

HEAVY RAIN IN LAST WEEK (Y/N)..

HABITAT

STREAM BED SUBSTRATE TYPE..(mud/sand/fine gravel/coarse gravel, cobble, boulder)

APPROXIMATE WATER DEPTH (CM)..

WATER QUALITY

WATER TEMPERATURE....................................... CONDUCTIVITY...................................... PH...................................

WATER COLOUR... (blue, green, tea coloured, other, uncoloured)

CLARITY ....(clear/milky/dirty)

WATER LEVEL(1-3)..(1=low, 2=normal, 3= high)

OTHER COMMENTS

APPENDIX THREE: BIASES

The New Zealand whitebait fishery involves thousands of fisherman harvesting millions of tiny fish from hundreds of rivers during a restricted season. This creates many problems and potential biases when trying to sample and characterise the whitebait catch. Logistical restraints meant I had to rely on recreational fisherman with no scientific background to sample from the whitebait catch. Once these samples had been obtained, I had to subsample them for morphological measurements. Each of the steps produced potential bias that needed to be managed carefully.

A3.1 Bias as a result of sample size

A3.1.1 Introduction

Rowe et al. (1992) found that samples in Bay of Plenty Rivers containing less than 100 fish were different from that of larger samples with 200 or more fish. Because of this variability they excluded samples with 100 or less fish. Therefore, in my study approximately 200 whitebait were taken from each river where possible.

Some larger catches of whitebait during the whitebait season of several thousand fish (ca. 1 kilogram) were examined from the: Avon River, (Canterbury); Rangitikei River, (Manawatu/Wanganui); Hokitika River, (Westland); and Waiatoto River, (Westland) to determine whether sample size influenced estimates of species composition (Fig. A3.1).

Large 1 kilogram samples were taken during November when the likelihood of detecting all five species was greatest. Approximately a kilogram of whitebait was caught over several hours of fishing. The catch was thoroughly mixed by hand and a single field subsample of approximately 200 fish using a known volume was taken from the larger catch. The remaining larger sample and smaller field subsample were labelled and frozen.

At a later date, the field subsample was processed for composition and morphometric data using methods outlined in Section 2.2. Once thawed, the larger remaining sample was remixed by hand and split into separate subsamples of approximately 200 fish before being processed.

Additional, field subsamples of approximately 200 fish were obtained from the Avon and Waiatoto Rivers at the same time as the 1 kilogram sample but not from the Rangitikei and Hokitika Rivers.

A3.1.2 Results

Composition

Inanga made up the highest proportions of species in each subsample followed by koaro, and banded kokopu. On the Avon River, koaro were present in 5 of the 9 laboratory subsamples from the 1 kilogram sample and the field subsample, but a single banded kokopu was present in only 1 of the 9 laboratory subsamples and not the field subsample. On the Waiatoto River proportions of inanga, koaro and banded kokopu were very similar between the field subsample and the total kilogram sample. Koaro and banded kokopu were present in all subsamples, but giant kokopu were found in only a single laboratory subsample (Fig. A3.1).

On the Rangitikei River, no simultaneous field subsample was taken. Koaro were present in all the laboratory subsamples, banded kokopu in 8 of the 9 laboratory subsamples and giant kokopu in 6 of 9 laboratory subsamples. A shortjaw kokopu was found in 1 of the 9 laboratory subsamples. On the Hokitika River, no simultaneous field subsample was taken. Koaro were present in all the laboratory subsamples, banded kokopu in 8 of the 9 subsamples and giant kokopu in 6 of 9 subsamples.

Approximately 200 fish in a subsample appeared to be representative of proportions of species in the larger 1 kilogram sample, but the larger samples had a greater chance of detecting less common species. Thus, sampling approximately 200 fish was adequate to detect relative proportions of species in catches.

Morphology

The length, weight and body depth of inanga were very similar in laboratory subsamples compared to the total 1 kilogram catch. However, there was variation in morphological measurements of koaro between laboratory subsamples (Fig. A3.2). This was probably due to the limited number of individual fish in these samples.

Size ranges were somewhat greater in the 1 kilogram catch however the medium, upper quartile and higher quartile were similar.

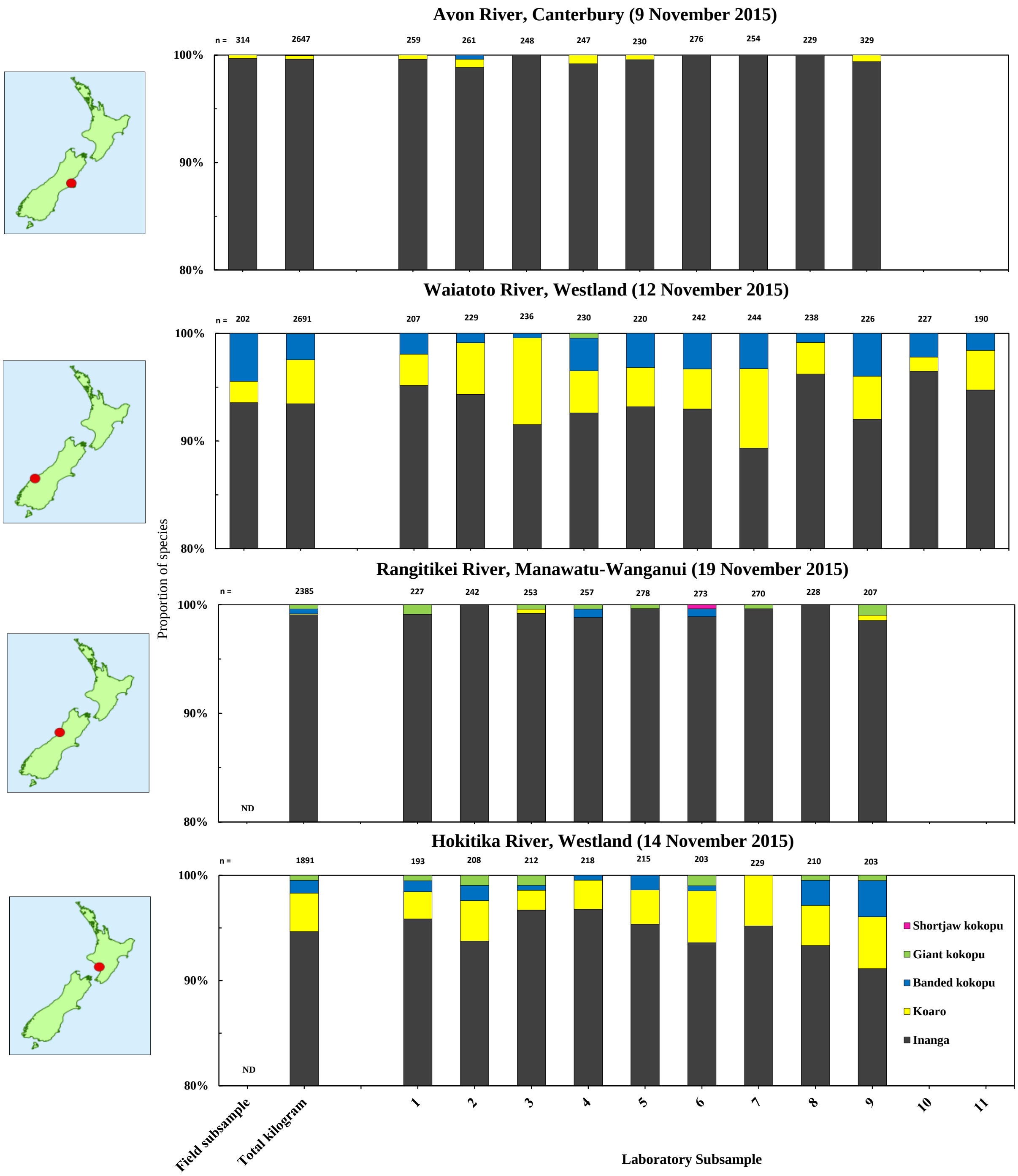


Figure A3.1. Species composition of whitebait catches in the Avon River (Canterbury), Waiatoto River (Westland), Rangitikei River (Manawatu-Wanganui) and Hokitika River (Westland). Where present, field samples of approximately 200 fish are contrasted with the mean of a larger one kilogram sample and laboratory sub-samples (approx. 200 fish). Note: the number on bars represent the number of fish in each subsample. Also, due to the high proportions of inanga in samples the y-axis is broken at the 80% level. ND = no data.
Samples sizes are shown above data points.

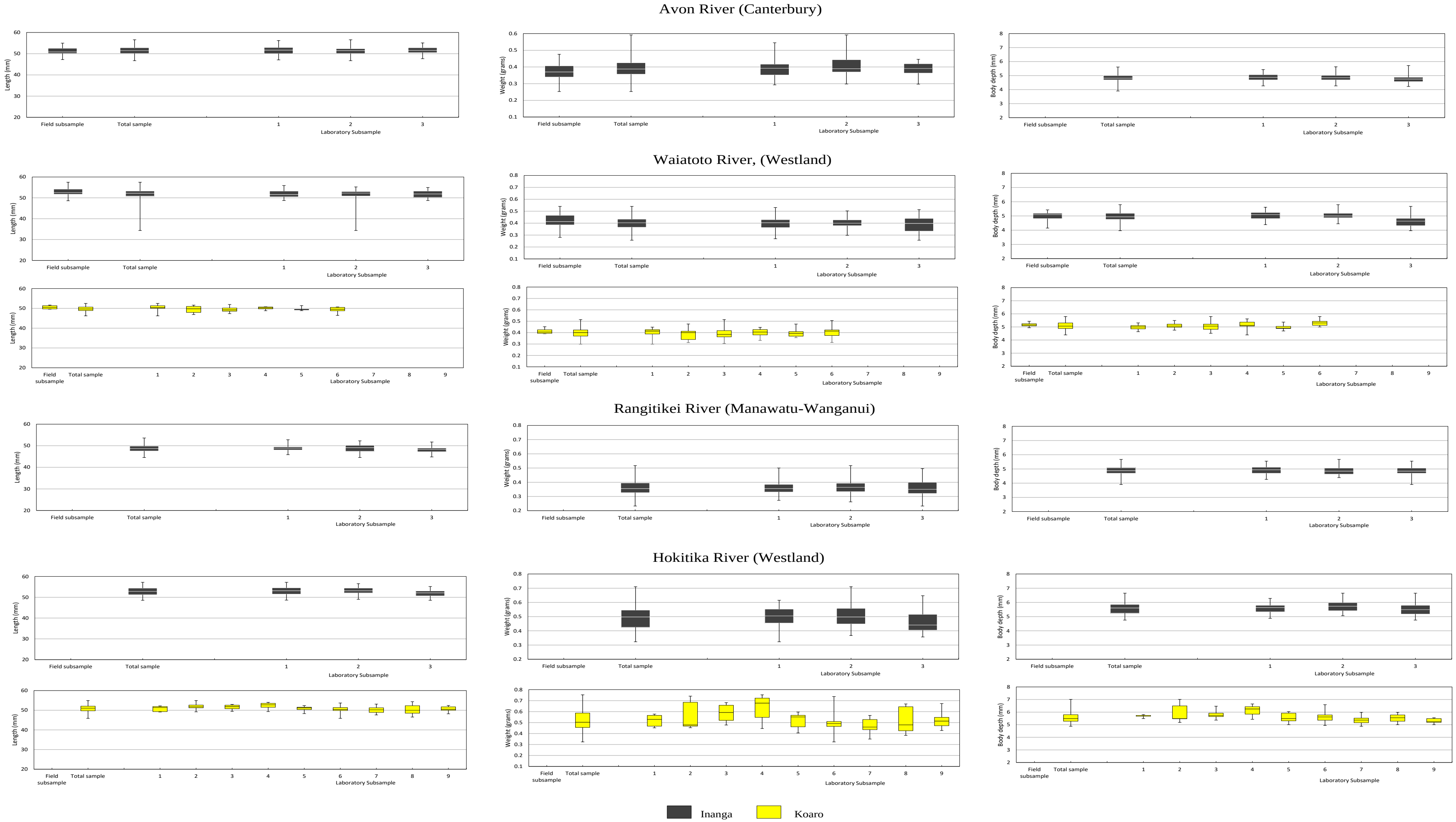


Figure A3.2. Box plots showing mean, minimum, maximum, first quartile and third quartile of total length, weight and body depth (±SE) of inanga (black), and koaro (yellow) sampled from whitebait catches in the Avon River (Canterbury), Waiatoto River (Westland), Rangitikei River (Manawatu-Wanganui) and Hokitika River (Westland). Where present, field samples of approximately 200 fish are contrasted with the mean of a larger one kilogram sample and laboratory sub-samples (approx. 200 fish).

A3.2 Bias as a result of fishing location

A3.2.1 Introduction

Past studies found differences in species composition depending on how far upstream whitebait were collected (Rowe et al., 1992). Sampling on the Waikato River (Waikato), Awakino River (Waikato), Waiatoto River (Westland), Taeri River (Otago), and Titiroa River (Southland) included both a downstream and an upstream site that were repeatedly sampled through time. Rivers were sampled where people catch whitebait. Where possible this was within the tidal reach within 1km of the river mouth (Fig. A3.3).

A Permutational Multivariate Analysis of Variance (PERMANOVA) was used to compare the composition of whitebait species assemblages between upstream and downstream sites for each river. For these tests, multiple samples collected through repeated sampling events were used as replicates (ensuring that for each sampling date both the upstream and downstream locations wer samples). The PERMANOVA was run in PRIMER V6 using a Bray-Curtis dissimilarity matrix on untransformed data. Each PERMANOVA had one fixed factor (Site: upstream vs downstream). The Monte Carlo test was used to increase the number of possible permutations when only a limited number of replicates was available.

A3.2.2 Results

In all the rivers, whitebait species compositions did not differ between upstream and downstream zones. There were slightly higher proportions of non-inanga species at upstream sites, but statistically there was no difference between sites on all rivers (Fig. A3.3). The Titiroa (Pseudo-$F_{1,2}$=1, P(MC) =0.424) Waiatoto (Pseudo-$F_{1,6}$=0.943, P(MC)=0.366) and Taeri Rivers (Pseudo-$F_{1,2}$=0.935, P(MC)=0.445) had the strongest relationship, whereas the Waikato (Pseudo-$F_{1,10}$=0.260, P(MC) 0.635), and Awakino (Pseudo-$F_{1,4}$=0.139, P(MC) 0.783) had the weakest relationships.

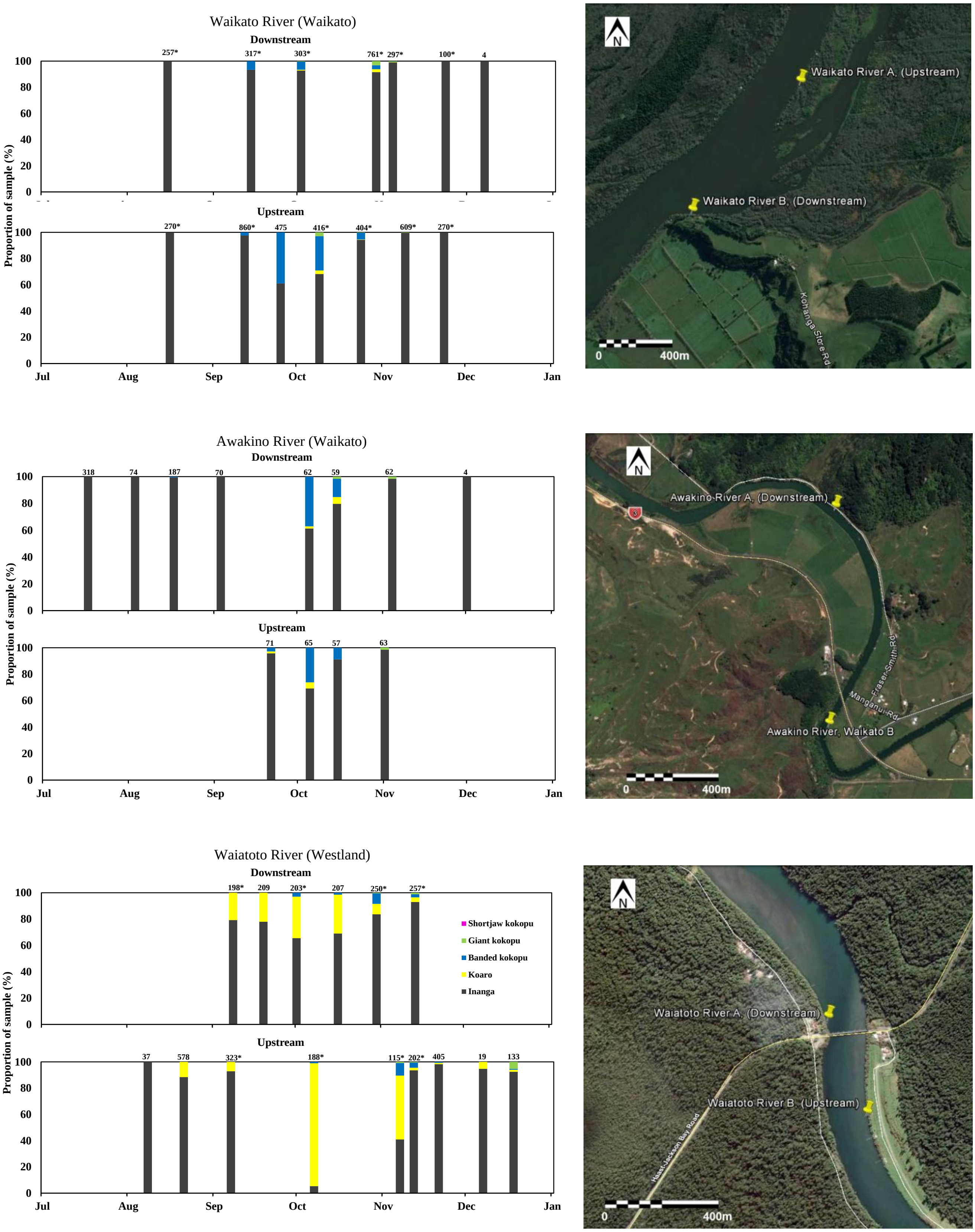
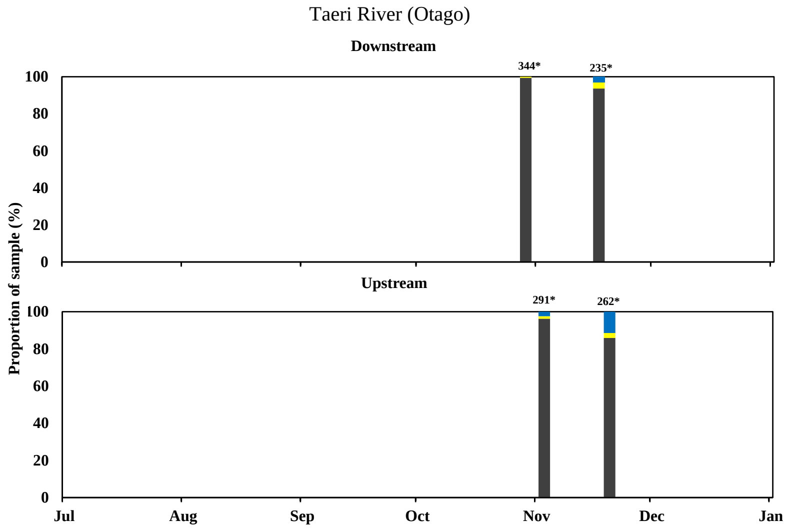


Figure A3.3. Species composition at upstream and downstream sites in the Waikato River (Waikato), Awakino River (Waikato), Taeri River (Otago) and Titiroa River (Southland).* = samples that were included in the analysis. Samples sizes are shown above data points.



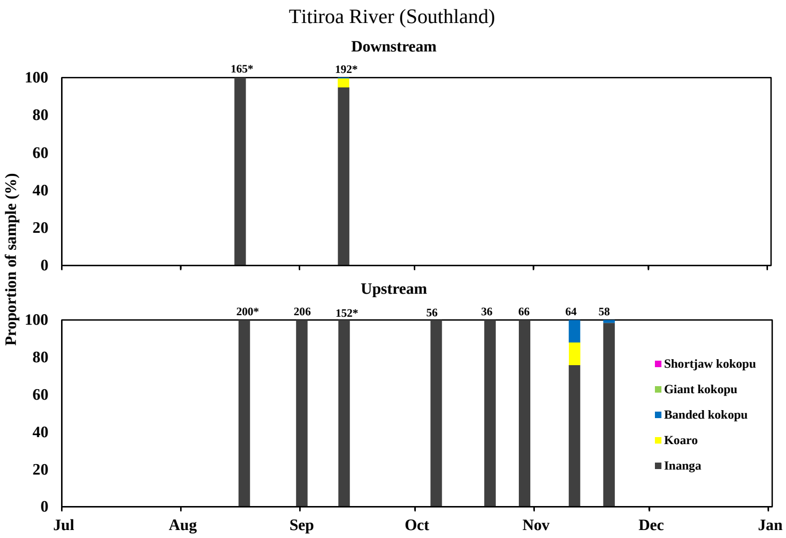


Figure A3.3 (continued).Species composition at upstream and downstream sites in the Waikato River (Waikato), Awakino River (Waikato), Taeri River (Otago) and Titiroa River (Southland). * = samples that were included in the analysis. Samples sizes are shown above data points.

A3.3 Other Biases

A3.3.1 Bias as a result of number of samples

Rowe et al. (1992) found that a single sample provided a good estimate of the species composition of a whitebaiters catch from a single site. Thus, generally only individual samples were taken from the same site during a particular time period.

A3.3.2 Bias as a result of fishing method

Rowe et al. (1992) found there to be a bias between species depending on whether a scoop or set net was used. Scoop netting was found to catch more *G. brevipinnis* and less *G. maculatus* than set netting.

A3.3.3 Bias as a result of other species being caught in the catch

Other non-galaxiid fish species are often caught in the whitebait catch including smelt (*Retropinna* sp.), bullies (*Gobiomorphus* sp.), paratya shrimps (*Paratya curvirostris*) and glass eels (*Anguilla* sp.). At times, smelt (*Retropinna* sp.), also known as second class whitebait can make up large proportions of the catch (McDowall, 1965). To reduce bias, smelt and other non-galaxiid species were returned to the river, but notes were made about their presence. The exceptions were the Waikato River Mouth and Katiuna River where whitebaiters failed to remove smelt.

A3.3.4 Bias as a result of preservation methods measuring and identifying samples after they are frozen

Morphological characteristics and pigmentation are important features used to identify species as whitebait. Previous whitebait composition studies preserved fish in 10% formalin and then were transferred to isopropropyl alcohol (McDowall & Eldon, 1980; Hanchet & Hayes, 1989; Rowe et al., 1992). Preservation of fish using formalin, alcohol and freezing has been found to cause shrinkage and changes the pigmentation that is helpful for species identification (Hopkins, 1979a; Neave et al., 2006; Niazie et al., 2013). Furthermore, preservation using formalin makes later genetic testing of specimens difficult (Dr Tania King, Univeristy of Otago, *pers comm*). Therefore, in my study fish were identified fresh where possible, and frozen in all other situations due to difficulties in distributing formalin and enable fish to be useable for genetic analysis.

Whitebait were measured and weighed to produce condition indices for each species. As the majority of samples were frozen a conversion factor was established by examining the changes in weight and length between fresh and frozen fish.

A conversion factor was measured for inanga, koaro and banded kokopu and the following equations can be used to predict fresh and frozen whitebait lengths and weights (Fig. A3.4).

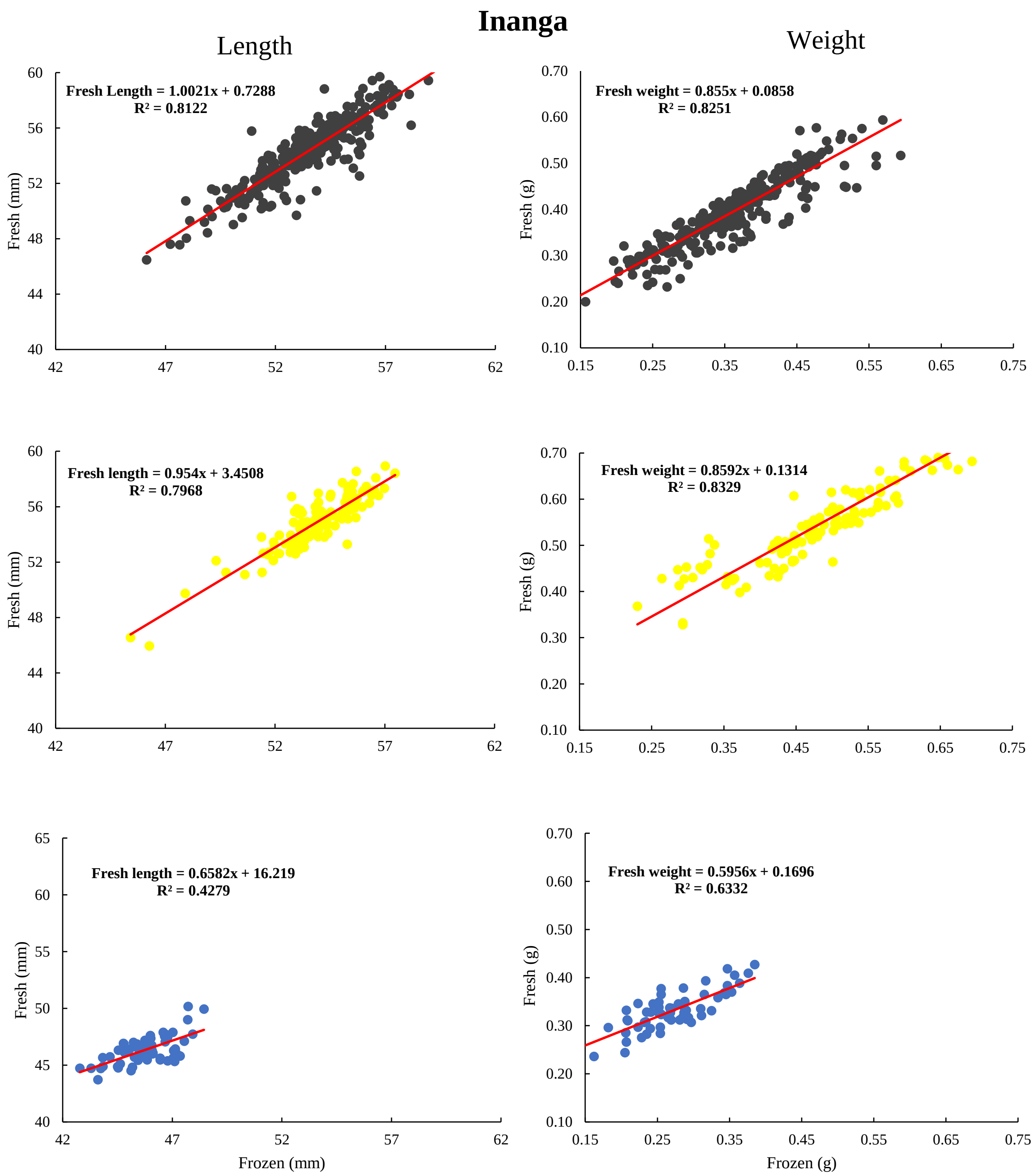


Figure A3.4. Conversion equations for total length and weight of whitebait: inanga (black), koaro (yellow), banded kokopu (blue) measured fresh and frozen.

APPENDIX FOUR: GENETIC IDENTIFICATION OF WHITEBAIT

A4.1 Whitebait tested genetically to confirm species identification: batch 1

Fish Number	Laboratory Identification	Certainty of identification	Justification where there was uncertainty	Genetic Identification	Fish (region, river, date)
1	*G. maculatus*	Definite		*G. maculatus*	BOP_KAITUNA_060915
2	*G. maculatus*	Definite		*G. maculatus*	BOP_KAITUNA_081015
3	*G. maculatus*	Definite		*G. maculatus*	WEST_WAIATOTO_080915
4	*G. maculatus*	Definite		*G. maculatus*	WEST_WAIATOTO_071015
5	*G. maculatus*	Definite	Very small fish at end of the season	*G. maculatus*	CAN_AVON_211215
6	*G. maculatus*	*99% sure*	Very clear fish with no melanophores, small mouth, skinny body, anal and dorsal fins opposite	*G. maculatus*	MARL_WAIRAU_131015
7	*G. fasciatus*	Definite		*G. fasciatus*	BOP_KAITUNA_060915
8	*G. fasciatus*	Definite		*G. fasciatus*	BOP_KAITUNA_081015
9	*G. fasciatus*	Definite		*G. fasciatus*	TASNEL_TAKAKA_011015
10	*G. fasciatus*	Definite		*G. fasciatus*	TASNEL_TAKAKA_150915
11	*G. fasciatus*	Definite		*G. fasciatus*	WEST_WAIATOTO_011015
12	*G. fasciatus or G.argenteus*	Uncertainty, large banded kokopu or giant kokopu	Mouth 1/4 to a third past eye, slight offset of anal and dorsal fin, similar size to banded kokopu, small gap anal to caudal fin	*G. fasciatus*	BOP_WHANGAPAROA_010915
13	*G. fasciatus or G.argenteus*	Uncertainty, large banded kokopu or giant kokopu	Much larger than banded kokopu in the sample, yet anal and dorsal fins are opposite, very short distance anal to caudal fin but mouth only 1/4 past the eye	*G. argenteus*	TASNEL_TAKAKA_021115
14	*G. fasciatus or G.argenteus*	Uncertainty, large banded kokopu or giant kokopu	Most likely banded kokopu but a little bigger than others	*G. fasciatus*	OTA_TAERI_171115
15	*G. fasciatus or G.argenteus*	Uncertainty, large banded kokopu or giant kokopu	Longer in length than koaro but shorter than banded kokopu, slight offset of anal and dorsal fin, mouth 1/4 past eye, gap between anal and caudal fin	*G. argenteus*	BULL_BULLER_181115

16	*G. fasciatus or G.argenteus*	Uncertainty, large banded kokopu or giant kokopu	All a similar length to banded kokopu with similar characteristics but fat and stocky	*G. argenteus*	WAIK_WAIKATO_091015
17	*G. fasciatus or G.argenteus*	Uncertainty, banded kokopu or giant kokopu	Like banded kokopu but distinct offset of anal and caudal, mouth only 1/4 past eye, appears too small for koaro, gap between anal and caudal	*G. argenteus*	WAIK_WAIKATO_091115
18	*G. brevipinnis*	Definite		*G. brevipinnis*	BOP_WHAKATANE_100915
19	*G. brevipinnis*	Definite		*G. postvectis*	BOP_WHAKATANE_051015
20	*G. brevipinnis*	Definite		*G. brevipinnis*	WEST_WAIATOTO_071015
21	*G. brevipinnis*	Definite		*G. brevipinnis*	WEST_WAIATOTO_121115
22	*G. brevipinnis*	Definite		*G. brevipinnis*	CAN_WAIMAKARIRI_061215
23	*G. brevipinnis or G. fasciatus*	Uncertainty, koaro or banded kokopu	Like other banded kokopu but fins slightly offset	*G. fasciatus*	WAIK_WENTWORTH_071015
24	*G. brevipinnis or G.argenteus*	Uncertainty koaro or giant kokopu	Could be koaro but very fat and stocky, slight offset of anal and dorsal fin, mouth 1/4 to 1/3 past eye, slight offset dorsal and anal fin, slight offset anal to caudal fin	*G. argenteus*	WAIK_AWAKINO_041115
25	*G. brevipinnis or G.argenteus*	Uncertainty koaro or giant kokopu	Could be giant kokopu with no real offset, different features to other regions	*G. argenteus*	WELL_PAUAHATANUI_241015
26	*G. brevipinnis or G.argenteus*	Uncertainty koaro or giant kokopu	Much larger and stockier than banded kokopu. Mouth 1/3rd past eye. Slight offset anal to dorsal fin, anal to caudal fin small gap	*G. argenteus*	MANWAN_RANGITIKEI_091115
27	*G. brevipinnis or G.argenteus*	Uncertainty koaro or giant kokopu	Almost no offset of anal and dorsal fin, small distance anal to caudal fin, mouth 1/3rd past eye, fish curved	*G. argenteus*	BULL_BULLER_021115
28	*G. brevipinnis or G.argenteus*	Uncertainty koaro or giant kokopu	Slight offset of anal and dorsal fin, similar size to other banded kokopu, mouth 1/4th past eye	*G. fasciatus*	AUCK_HOTEO_191115
29	*G. argenteus*	Definite	Captive-reared fish from Mahurangi Technical Institute	*G. argenteus*	AUCK_MTI_091115_PAUL
30	*G. argenteus*	Definite	Captive-reared fish from Mahurangi Technical Institute	*G. argenteus*	AUCK_MTI_091115_PAUL
31	*G. argenteus*	99% sure	Much fatter and stockier than koaro but larger than banded kokopu, slight offset of anal and dorsal fin, mouth 1/3rd past eye, small gap anal to caudal fin	*G. argenteus*	WEST_WAIATOTO_301015
32	*G. argenteus*	Uncertainty, but likely giant kokopu	Mouth 1/3rd past eye, almost no offset anal and dorsal fin	*G. argenteus*	BULL_PUNANKAIKI_181115
33	*G. argenteus*	Uncertainty, but likely giant kokopu	As stocky as koaro but shorter in length, only slight offset of anal and dorsal fin, mouth 1/3rd past eye	*G. brevipinnis*	WEST_WANGANUI_081115

34	*G. argenteus*	Uncertainty, but likely	Likely giant kokopu, larger and stockier than banded kokopu, slight offset of anal and dorsal fin, mouth 1/3 past eye, only small gap anal to caudal fin	*G. argenteus*	WEST_OKARITO_301015
35	*G. argenteus*	Uncertainty, but likely giant kokopu	Mouth 1/3rd to 1/2 past eye, no offset anal and dorsal, small gap anal to caudal fin	*G. argenteus*	BULL_OROWAITI_091115
36	*G. argenteus*	Uncertainty, but likely giant kokopu	Distinct mouth 1/2past eye, only slight offset of anal and dorsal fin, short gap between anal and caudal fin	*G. argenteus*	WEST_WANGANUI_191115
37	*G. argenteus*	Uncertainty, but likely giant kokopu	Slightly bigger and fatter than banded kokopu, anal and dorsal fin slightly offset, mouth 1/3 past eye whereas banded kokopu were only 1/4 past eye, short distance anal to caudal fin	*G. argenteus*	WAIK_MOKAU_181115
38	*G. argenteus*	Uncertainty, but likely giant kokopu	Fish stockier and fatter than koaro, slight offset of anal and dorsal fin, mouth 1/3rd past eye, short distance anal to caudal	*G. argenteus*	MANWAN_OWAHANGA_171115
39	*G. argenteus*	Uncertainty, but likely giant kokopu	Mouth 1/3rd past eye, slight offset of anal and caudal fin, anal to caudal fin very short	*G. argenteus*	MANWAN_RANGITIKEI_191115
40	*G. argenteus*	Uncertainty, but likely giant kokopu	Most likely giant kokopu, mouth 1/3rd past eye, no real offset of anal and dorsal fins shorter in length than koaro and somewhat stockier, small gap between the anal and caudal fin	*G. argenteus*	TASNEL_TAKAKA_161015
41	*G. argenteus*	Uncertainty, but likely giant kokopu	Very slight offset of anal and dorsal fin, mouth 1/3rd past eye, small gap anal to caudal fin, similar size to koaro	*G. argenteus*	TASNEL_WAINUI_191015
42	*G. argenteus*	Uncertainty, could be giant kokopu	Appeared different from other koaro in the sample, could be giant kokopu	*G. brevipinnis*	SOUTH_MATAURA_301115
43	*G. argenteus*	Uncertainty, likely giant kokopu	Slight offset of anal and dorsal fins. Mouth 1/3rd past eye, short distance anal to caudal fin	*G. argenteus*	BULL_MOKIHINUI_171115
44	*G.argenteus or G. brevipinnis*	Uncertainty, but likely giant kokopu	Slight offset of anal and dorsal fin, mouth 1/3rd past eye, reasonable distance anal to caudal fin	*G. argenteus*	BULL_MOKIHINUI_171115
45	*G. argenteus or G. fasciatus*	Uncertainty, likely giant kokopu or large banded kokopu	Larger than BK but smaller than koaro, mouth 1/4 to 1/3 past eye, slight offset of anal and dorsal fin, gap anal to caudal fin	*G. argenteus*	WAIK_WAIKATO_041115
46	*G. argenteus or G. fasciatus*	Uncertainty, banded kokopu or could be giant kokopu	Could be giant kokopu but mouth goes only just past eye, could be large banded kokopu	*G. argenteus*	WELL_PAUAHATANUI_141015
47	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Very skinny slim fish more like inanga shape, lower bottom jaw, mouth to eye, distinct offset of anal and dorsal fin, very different so best to check	*G. brevipinnis*	SOUTH_APARIMA_151015
48	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Much fatter and stockier than other koaro, slightly shorter, distinct offset of anal and caudal fin, short distance anal to caudal fin	*G. postvectis*	BULL_BULLER_021115
49	*G. postvectis or G. brevipinnis*	Uncertainty, could be koaro or shortjaw kokopu	Mouth not even to eye, very large and stocky, distinct offset of anal and dorsal fin, short gap anal to caudal fin	*G. postvectis*	BULL_OROWAITI_091115
50	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	All characteristics of a koaro but with an extremely short lower jaw	*G. brevipinnis*	BULL_OPARARA_111015
51	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Mouth stops at eye, only a slight offset of anal and dorsal fin, large split underneath	*G. argenteus*	WAIK_WAIKATO_091015

A4.2 Whitebait tested genetically to confirm species identification: batch 2

Fish Number	Laboratory Identification	Certainty of identification	Justification where there was uncertainty	Genetic Identification	Fish (region, river, date)
52	*G. brevipinnis*	Definite	In last test koaro was in fact shortjaw thus another koaro selected	*G. brevipinnis*	BOP_WHAKATANE_051015
53	*G. brevipinnis*	99% sure	Good to double check that koaro are there	*G. brevipinnis*	BOP_KAITUNA_230915
54	*G. brevipinnis*	Uncertainty but likely koaro	Very small fish, slight offset of anal and dorsal, confirmation wanted	*G. brevipinnis*	BOP_WHAKATANE_010915
55	*G. brevipinnis* or *G. argenteus*	Uncertainty koaro or giant kokopu	Same size and shape of koaro, only slight offset of anal and dorsal fin, mouth 1/4 to 1/3rd past eye, smaller gap between anal and caudal fin but still gap	*G. brevipinnis*	WEST_WAIATOTO_011015
56	*G. brevipinnis* or *G. argenteus*	Uncertainty koaro or giant kokopu	Very fat and stocky for koaro, mouth 1/4 past the eye, short distance anal to caudal fin, anal and dorsal fin offset	*G. argenteus*	WAIK_WAIKATO_021015
57	*G. brevipinnis* or *G. argenteus*	Uncertainty, likely koaro but could be giant kokopu	Slight offset of anal and dorsal fin, gap anal to caudal fin, mouth 1/3 past eye, not as fat and stocky as fish 82 in sample	*G. argenteus*	TASNEL_TAKAKA_301115
58	*G. brevipinnis* or *G. argenteus*	Uncertainty, koaro or giant kokopu	Shorter than other fish confirmed as koaro	*G. brevipinnis*	SOUTH_MATAURA_301115
59	Unknown	Uncertainty but could be koaro	Distinct offset, shape of inanga, shorter lower jaw, some split underneath but nor significant	*G. brevipinnis*	WAIK_WAIKATO_091015
60	*G. argenteus*	Definite		*G. argenteus*	WEST_HOKITIKA_141115
61	*G. argenteus*	Definite		*G. argenteus*	WEST_WAIMEA_281115
62	*G. argenteus*	99% sure but different offset of anal and dorsal	Different offset of anal and dorsal fin, mouth only 1/4 to 1/3 past eye	*G. argenteus*	WEST_WAIATOTO_181215
63	*G. argenteus*	Uncertainty, but likely giant kokopu	Likely giant kokopu after first genetic identifications, mouth 1/3 past eye, slight offset of anal and dorsal fin, stocky and fat	*G. argenteus*	WAIK_WAIKATO_291015
64	*G. argenteus*	Uncertainty, but likely giant kokopu	Likely giant kokopu after first genetic identifications, mouth 1/3 past eye, slight offset of anal and dorsal fin, skinny	*G. argenteus*	WAIK_WAIKATO_291015
65	*G. argenteus*	Uncertainty, but likely giant kokopu	Not 100% sure, slightly offset anal and dorsal fin, no gap anal to caudal fin, mouth only 1/4 to 1/3 past eye, much fatter than banded kokopu but similar length, much shorter in length than koaro and fatter	*G. argenteus*	WEST_WAIATOTO_121115
66	*G. argenteus*	Uncertainty, but likely giant kokopu	Slight offset of anal and dorsal, short distance anal to caudal, mouth 1/2 past eye	*G. argenteus*	WAIK_WAIKAWAU_261015

67	*G. argenteus*	Uncertainty, but likely giant kokopu	Slight offset of anal and dorsal fin, mouth 1/4 past eye, smaller pectoral fin than expected in a giant kokopu, appears to be giant kokopu from pictures	*G. argenteus*	WEST_WAIATOTO_071115
68	*G. argenteus*	Uncertainty, but likely giant kokopu	fish missing part of tail so hard to tell, slight offset anal and dorsal fin, mouth 1/3rd past eye, short distance anal to caudal fin	*G. argenteus*	WAIK_AWAKINO_151015
69	*G. fasciatus*	99% sure	I wanted to confirm banded kokopu from this region	*G. fasciatus*	CAN_SALTWATER_231215
70	*G. fasciatus*	Uncertainty, but likely banded kokopu	Mouth 1/3rd past eye, only slight offset	*G. fasciatus*	WEST_HOKITIKA_141115
71	*G. fasciatus*	Uncertainty, likely banded kokopu but could be giant kokopu	Very likely banded kokopu but confirmation needed, mouth goes 1/4/ to 1/3 past eye, anal and dorsal directly offset	*G. fasciatus*	SOUTH_TITIROA_111115
72	*G. fasciatus or G. argenteus*	Uncertainty, banded kokopu but could be giant kokopu	Bigger than other banded kokopu but doesn't fit anything else, no offset of anal and dorsal, mouth to eye and reasonable distance anal and caudal fin	*G. fasciatus*	WAIK_WAIKATO_021015
73	*G. fasciatus or G. argenteus*	Uncertainty, banded kokopu or giant kokopu	Similar to other banded kokopu but slight offset of anal and dorsal fin	*G. argenteus*	MANWAN_RANGITIKEI_191115
74	*G. fasciatus or G. argenteus*	Uncertainty, banded kokopu or giant kokopu	Mouth 1/3 the way past eye, no distinct offset of anal and dorsal	*G. fasciatus*	WAIK_WAIKATO_241015
75	*G. fasciatus or G. argenteus*	Unknown but could be stocky banded kokopu	Looked like banded kokopu from picture, no offset of anal and dorsal fin, mouth 1/4 past the eye, bottom jaw slightly shorter than upper jaw	*G. fasciatus*	WEST_WAIATOTO_211115
76	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Likely koaro but has a distinct short jaw, offset anal and dorsal, big and stocky	*G. brevipinnis*	WEST_HOKITIKA_141115
77	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Likely koaro but slightly bigger than other fish, mouth 1/4 past eye, distinct offset anal and dorsal	*G. brevipinnis*	TASNEL_WAINUI_191015
78	*G. postvectis or G. brevipinnis*	Uncertainty, could be short jaw kokopu	Like koaro but with distinct shortjaw. Much bigger than giant kokopu and banded kokopu	*G. postvectis*	WEST_WAIMEA_071115
79	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Size of koaro but mouth not even to eye, no distinct shortjaw, very large and stocky, small gap anal to caudal fin	*G. postvectis*	MANWAN_RANGITIKEI_191115
80	*G. postvectis or G. brevipinnis*	Uncertainty, likely koaro but could be shortjaw kokopu	Distinct offset anal and dorsal, mouth to eye, long tail end like inanga, very short lower jaw	*G. brevipinnis*	WEST_WAIATOTO_071215
81	*Retropinna retropinna*	Definite	Submitted to test validity of species identifications	Failed sequence	WAIK_MOKAU_011215

Highlighter blue = indicates whitebait where identifications do not match laboratory identification.

Regions: WAIK (Waikato), BOP (Bay of Plenty), WELL (Wellington), MANWAN (Manawatu-Wanganui), AUCK (Auckland), OTA (Otago), MARL (Marlborough), WEST (Westland), SOUTH (Southland), CAN (Canterbury), BULL (Buller), TASNEL (Tasman-Nelson),

APPENDIX FIVE: TEMPORAL MORPHOLOGY ANALYSIS RESULTS WITHIN RIVERS

Table A5.1. ANOVA results of variation seen in species lengths from July to December.

Region	River	Species	Source of variation	SS	df	F	P
Waikato	**Waikato**	**Inanga**	**Months**	1199.6	9	47.3	<0.001
			Residual	1071.5	380		
		Koaro	**Months**	0.03	1	0.01	<0.92
			Residual	69.92	23		
		Banded kokopu	**Months**	36.53	6	5.86	<0.001
			Residual	150.76	145		
		Giant kokopu	**Months**	2.31	1	1.26	0.27
			Residual	66.01	36		
	Mokau	**Inanga**	**Months**	1519	9	69.4	<0.001
			Residual	1443	593		
		Banded kokopu	**Months**	0.97	1	1.08	0.30
			Residual	72.84	81		
	Awakino	**Inanga**	**Months**	621.4	8	28.8	<0.001
			Residual	849.7	315		
		Banded kokopu	**Months**	10.69	1	7.5	<0.05
			Residual	28.50	20		
Manawatu-Wanganui	**Rangitikei**	**Inanga**	**Months**	455.6	6	24.5	<0.001
			Residual	976.5	315		
		Koaro	**Months**	36.8	3	5.58	<0.01
			Residual	184.9	84		
		Banded kokopu	**Months**	24.40	4	5.92	<0.001
			Residual	39.13	38		
Bay of Plenty	**Whakatane**	**Inanga**	**Months**	253.5	4	17.4	<0.001
			Residual	635.8	175		
		Koaro	**Months**	332.87	3	49.17	<0.001
			Residual	106.05	47		
	Kaituna	**Inanga**	**Months**	1052.4	8	43.0	<0.001
			Residual	1583.4	518		

Hawkes Bay	**Tutaekuri**	**Inanga**	**Months**	32.27	7	32.2	<0.001
			Residual	44.17	277		
		Koaro	**Months**	32.27	1	15.34	<0.001
			Residual	44.17	21		
		Banded kokopu	**Months**	0.99	1	0.83	0.38
			Residual	14.27	12		
Tasman-Nelson	**Takaka**	**Inanga**	**Months**	1231	11	39.9	<0.001
			Residual	1169	417		
		Koaro	**Months**	85.4	5	4.5	<0.001
			Residual	770.2	202		
		Banded kokopu	**Months**	419.6	4	89.6	<0.001
			Residual	185.0	158		
	Wainui River	**Inanga**	**Months**	389.8	4	34.9	<0.001
			Residual	374.1	134		
		Koaro	**Months**	60.35	2	6.86	<0.01
			Residual	145.09	33		
		Banded kokopu	**Months**	171.2	2	87.1	<0.001
			Residual	102.2	104		
Marlborough	**Wairau Diversion**	**Inanga**	**Months**	48.0	4	5.0	<0.001
			Residual	414.7	172		
		Banded kokopu	**Months**	0.12	1	0.13	0.73
			Residual	11.33	12		
Buller	**Mokihinui**	**Inanga**	**Months**	173.0	3	21.24	<0.001
			Residual	304.0	112		
		Koaro	**Months**	56.8	3	5.43	<0.01
			Residual	352.0	101		
		Banded kokopu	**Months**	49.9	3	17.9	<0.001
			Residual	93.9	101		
	Buller	**Inanga**	**Months**	99.2	4	8.7	<0.001
			Residual	518.0	182		
		Koaro	**Months**	146.5	4	20.1	<0.001
			Residual	282.4	155		

		Banded kokopu	**Months**	5.67	2	2.64	0.08
			Residual	58.98	55		
	Punankaiki	**Inanga**	**Months**	527.8	3	53.31	<0.001
			Residual	376.3	114		
		Koaro	**Months**	24.46	2	6.50	<0.01
			Residual	86.51	46		
Westland	**Waimea Creek**	**Inanga**	**Months**	455.8	4	48.4	<0.001
			Residual	339.2	144		
		Banded kokopu	**Months**	25.24	1	27.97	<0.001
			Residual	36.11	40		
		Giant kokopu	**Months**	0.80	1	0.46	0.50
			Residual	79.64	46		
	Hokitika	**Inanga**	**Months**	170.2	6	8.8	<0.001
			Residual	960.1	299		
		Koaro	**Months**	270.4	3	36.87	<0.001
			Residual	320.2	131		
		Banded kokopu	**Months**	21.5	2	14.1	<0.001
			Residual	51.0	67		
	Wanganui	**Inanga**	**Months**	296.8	6	24.3	<0.001
			Residual	486.9	239		
		Koaro	**Months**	25.13	2	5.14	<0.05
			Residual	70.90	29		
		Banded kokopu	**Months**	0.04	1	0.04	0.84
			Residual	10.50	12		
	Waiatoto	**Inanga**	**Months**	1145.9	12	29.9	<0.001
			Residual	1593.5	499		
		Koaro	**Months**	824.5	8	58.5	<0.001
			Residual	613.2	348		
		Banded kokopu	**Months**	45.61	3	11.67	<0.001
			Residual	121.12	93		
	Cascade	**Inanga**	**Months**	110.9	5	8.0	<0.001
			Residual	595.3	215		

		Koaro	**Months**	88.9	4	5.55	<0.001
			Residual	300.0	75		
		Banded kokopu	**Months**	12.31	2	6.50	<0.01
			Residual	26.52	28		
Canterbury	**Saltwater Creek**	**Inanga**	**Months**	464.1	5	23.0	<0.001
			Residual	847.1	210		
	Avon	**Inanga**	**Months**	92.3	6	4.5	<0.001
			Residual	1159.2	340		
	Waimakeriri	**Inanga**	**Months**	221.5	7	10.0	<0.001
			Residual	868.3	274		
Southland	**Waiau**	**Inanga**	**Months**	329.1	8	14.7	<0.001
			Residual	878.2	314		
		Koaro	**Months**	98.7	2	32.1	<0.001
			Residual	149.3	97		
		Banded kokopu	**Months**	47.05	1	41.78	<0.001
			Residual	25.90	23		
	Aparima	**Inanga**	**Months**	332.6	7	15.5	<0.001
			Residual	844.2	276		
	Mataura	**Inanga**	**Months**	294.5	3	33.5	<0.001
			Residual	416.6	142		
		Koaro	**Months**	4.31	1	2.17	0.15
			Residual	77.45	39		
	Titiroa	**Inanga**	**Months**	65.6	5	4.8	<0.001
			Residual	508.0	187		
		Koaro	**Months**	37.02	1	14.89	<0.01
			Residual	34.80	2.49		

Table A5.2. ANOVA results of variation seen in species condition from July to December.

Region	River	Species	Source of variation	SS	df	MS	F	P
Waikato	**Waikato**	**Inanga**	**Months**	12373.28	8.00	1546.66	21.43	<0.001
			Residual	24897.08	345.00	72.17		
		Koaro	**Months**	14.84	1.00	14.84	0.12	0.74
			Residual	2959.14	23.00	128.66		
		Banded kokopu	**Months**	6161.35	4.00	1540.34	30.11	<0.001
			Residual	6446.70	126.00	51.16		
		Giant kokopu	**Months**	21.59	1.00	21.59	0.39	0.54
			Residual	1981.20	36.00	55.03		
	Mokau	**Inanga**	**Months**	11384.97	9.00	1265.00	15.45	<0.001
			Residual	48564.08	593.00	81.90		
		Banded kokopu	**Months**	1035.76	1.00	1035.76	9.77	<0.01
			Residual	8589.72	81.00	106.05		
	Awakino	**Inanga**	**Months**	4771.48	8.00	596.44	9.12	<0.001
			Residual	20597.24	315.00	65.39		
		Banded kokopu	**Months**	1.04	1.00	1.04	0.02	0.88
			Residual	911.89	20.00	45.59		
Manawatu-Wanganui	**Rangitikei**	**Inanga**	**Months**	32595.36	6.00	5432.56	73.09	<0.001
			Residual	23411.85	315.00	74.32		
		Koaro	**Months**	11193.84	3.00	3731.28	34.14	<0.001
			Residual	9179.43	84.00	109.28		
		Banded kokopu	**Months**	8603.65	3.00	2867.88	40.26	<0.001
			Residual	2350.85	33.00	71.24		
Bay of Plenty	**Whakatane**	**Inanga**	**Months**	16673.33	4.00	4168.33	76.53	<0.001
			Residual	9532.12	175.00	54.47		
		Koaro	**Months**	5928.98	3.00	1976.33	43.63	<0.001
			Residual	2128.97	47.00	45.30		
	Kaituna	**Inanga**	**Months**	23647.76	8.00	2955.97	48.11	<0.001
			Residual	31824.86	518.00	61.44		
Hawkes Bay	**Tutaekuri**	**Inanga**	**Months**	17980.31	7.00	2568.62	30.67	<0.001
			Residual	23198.39	277.00	83.75		

		Koaro	**Months**	341.01	1.00	341.01	8.53	<0.01
			Residual	839.92	21.00	40.00		
		Banded kokopu	**Months**	467.24	1.00	467.24	11.05	<0.01
			Residual	507.61	12.00	42.30		
Tasman-Nelson	**Takaka**	**Inanga**	**Months**	36667.68	11.00	3333.43	46.08	<0.001
			Residual	30095.16	416.00	72.34		
		Koaro	**Months**	13392.67	5.00	2678.53	35.78	<0.001
			Residual	15120.59	202.00	74.85		
		Banded kokopu	**Months**	6570.28	4.00	1642.57	27.93	<0.001
			Residual	9293.19	158.00	58.82		
	Wainui River	**Inanga**	**Months**	5660.78	4.00	1415.19	21.86	<0.001
			Residual	8673.61	134.00	64.73		
		Koaro	**Months**	193.09	2.00	96.55	0.94	0.40
			Residual	3399.43	33.00	103.01		
		Banded kokopu	**Months**	837.49	2.00	418.75	6.87	<0.01
			Residual	6336.50	104.00	60.93		
Marlborough	**Wairau Diversion**	**Inanga**	**Months**	13452.43	3.00	4484.14	74.20	<0.001
			Residual	8339.64	138.00	60.43		
Buller	**Mokihinui**	**Inanga**	**Months**	15528.70	4.00	3882.17	44.62	<0.001
			Residual	10179.83	117.00	87.01		
		Koaro	**Months**	5171.19	3.00	1723.73	14.61	<0.001
			Residual	11918.92	101.00	118.01		
		Banded kokopu	**Months**	24531.75	3.00	8177.25	150.26	<0.001
			Residual	5496.52	101.00	54.42		
	Buller	**Inanga**	**Months**	16598.64	4.00	4149.66	64.60	<0.001
			Residual	11691.86	182.00	64.24		
		Koaro	**Months**	9398.30	4.00	2349.57	22.39	<0.001
			Residual	16262.95	155.00	104.92		
		Banded kokopu	**Months**	6706.03	2.00	3353.01	50.82	<0.001
			Residual	3628.89	55.00	65.98		
	Punankaiki	**Inanga**	**Months**	3143.16	3.00	1047.72	9.14	<0.001
			Residual	13072.04	114.00	114.67		

		Koaro	**Months**	276.19	2.00	138.10	3.36	<0.05
			Residual	1891.44	46.00	41.12		
Westland	**Waimea Creek**	**Inanga**	**Months**	0.10	4.00	0.02	20.37	<0.001
			Residual	0.17	144.00	0.00		
		Banded kokopu	**Months**	179.77	1.00	179.77	3.80	0.06
			Residual	1891.86	40.00	47.30		
		Giant kokopu	**Months**	5.51	1.00	5.51	0.27	0.60
			Residual	954.60	47.00	20.31		
	Hokitika	**Inanga**	**Months**	0.96	6.00	0.16	114.08	<0.001
			Residual	0.42	299.00	0.00		
		Koaro	**Months**	0.04	3.00	0.01	8.73	<0.001
			Residual	0.19	131.00	0.00		
		Banded kokopu	**Months**	119.55	2.00	59.78	0.88	0.42
			Residual	4576.56	67.00	68.31		
	Wanganui	**Inanga**	**Months**	5575.13	6.00	929.19	14.56	<0.001
			Residual	15251.73	239.00	63.81		
		Koaro	**Months**	480.13	2.00	240.06	2.36	0.11
			Residual	2952.54	29.00	101.81		
		Banded kokopu	**Months**	113.77	1.00	113.77	1.35	0.27
			Residual	1012.70	12.00	84.39		
	Waiatoto	**Inanga**	**Months**	13861.95	12.00	1155.16	17.71	<0.001
			Residual	32552.04	499.00	65.23		
		Koaro	**Months**	14351.00	8.00	1793.88	43.61	<0.001
			Residual	14315.01	348.00	41.14		
		Banded kokopu	**Months**	126.83	4.00	31.71	0.60	0.66
			Residual	4877.02	93.00	52.44		
	Cascade	**Inanga**	**Months**	4967.49	5.00	993.50	10.60	<0.001
			Residual	20156.67	215.00	93.75		
		Koaro	**Months**	5624.25	4.00	1406.06	28.54	<0.001
			Residual	3694.84	75.00	49.26		
		Banded kokopu	**Months**	4933.19	2.00	2466.60	50.68	<0.001
			Residual	1362.78	28.00	48.67		

Canterbury	**Saltwater Creek**	**Inanga**	**Months**	11340.62	5.00	2268.12	25.23	<0.001
			Residual	18874.87	210.00	89.88		
	Avon	**Inanga**	**Months**	32668.34	6.00	5444.72	76.59	<0.001
			Residual	24169.66	340.00	71.09		
	Waimakeriri	**Inanga**	**Months**	39128.34	6.00	6521.39	73.52	<0.001
			Residual	21110.60	238.00	88.70		
Southland	**Waiau**	**Inanga**	**Months**	28032.58	8.00	3504.07	54.17	<0.001
			Residual	20310.09	314.00	64.68		
		Koaro	**Months**	219.57	2.00	109.79	1.91	0.15
			Residual	5531.00	96.00	57.61		
		Banded kokopu	**Months**	265.74	1.00	265.74	5.77	<0.05
			Residual	1059.31	23.00	46.06		
	Aparima	**Inanga**	**Months**	27927.66	7.00	3989.67	82.42	<0.001
			Residual	13359.80	276.00	48.41		
	Mataura	**Inanga**	**Months**	2311.99	3.00	770.66	12.14	<0.001
			Residual	9014.35	142.00	63.48		
		Koaro	**Months**	0.11	1.00	0.11	0.00	0.96
			Residual	1746.79	39.00	44.79		
	Titiroa	**Inanga**	**Months**	3427.30	5.00	685.46	9.06	<0.001
			Residual	14149.17	187.00	75.66		
		Koaro	**Months**	624.50	1.00	624.50	17.28	<0.001
			Residual	506.01	14.00	36.14		